APPROVAL STANDARD

INTRINSICALLY SAFE APPARATUS

AND ASSOCIATED APPARATUS

FOR USE IN

CLASS I, II AND III, DIVISION 1

HAZARDOUS (CLASSIFIED) LOCATIONS

CLASS NUMBER 3610

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II SCOPE

2.1* APPLICATION

This standard shall apply to:

(1) Apparatus or parts of apparatus in Class I, II or III, Division 1 locations as defined by the National Electrical Code, NFPA-70.

NOTE: SECTION 500-3(A) OF NFPA 70-1987, NATIONAL ELECTRICAL CODE, STATES THAT EQUIPMENT APPROVED FOR DIVISION 1 LOCATIONS SHALL BE PERMITTED IN DIVISION 2 LOCATIONS OF THE SAME CLASS AND GROUP.

(2) Associated apparatus located outside of the Class I, II or III, Division 1 location whose design and construction may influence the intrinsic safety of an electrical circuit within the Class I, II or III, Division 1 location.

2.2* REQUIREMENTS

These requirements are based on consideration of ignition in locations made hazardous by the presence of flammable or combustible material under normal atmospheric conditions.

2.2.1 For the purposes of this standard, normal atmospheric conditions are considered to be:

(1) an ambient temperature of 40°C (104°F);
(2) an oxygen concentration not greater than 21 percent;
and (3) a pressure of one atmosphere.

2.3 MECHANISMS OF IGNITION

2.3.1 This standard does not cover mechanisms of ignition from external sources such as static electricity or lightning, which are not related to the electrical characteristics of the apparatus. However, the possibility of static charge on polymeric materials and ungrounded metal parts shall be considered during the Approval examination.

2.3.2 This standard does not cover apparatus based on high voltage electrostatic principles (i.e., electrostatic paint spraying).

2.4 APPLICABILITY OF OTHER STANDARDS

2.4.1* Except where modified by the requirements of this standard, intrinsically safe and associated apparatus shall comply with the applicable requirements for ordinary locations, in accordance with Factory Mutual Approval Standard 3810.

2.4.2 Associated apparatus and circuits shall conform to the requirements of the location in which they are installed.

2.5* CONTROL DRAWING

A control drawing shall be provided for all intrinsically safe apparatus or associated apparatus that requires interconnection to other circuits or apparatus resulting in an intrinsically safe system.

2.5.1 An intrinsically safe system could consist of the interconnection of intrinsically safe apparatus and associated apparatus investigated as a system, or the interconnection of such apparatus separately investigated under the entity evaluation concept.

2.5.2 The control drawing for intrinsically safe and associated apparatus investigated as a system shall provide the following:

(a) the polarity requirements for proper connection;
(b) the hazardous location in which the apparatus may be installed; and
(c) identification of the apparatus which may be interconnected;
(d) grounding requirements for associated apparatus if essential to intrinsic safety.

2.5.3 The control drawing for the apparatus investigated under the entity evaluation concept shall provide the following information:

(a) for associated apparatus:

(1) maximum output voltage, (Voc);
(2) maximum output current, (Isc);
(3) maximum allowed capacitance, (Ca); and
(4) maximum allowed inductance, (La);

(b) for intrinsically safe apparatus:

(1) maximum input voltage, (Vmax);
(2) maximum input current, (Imax);
(3) maximum internal capacitance, (Ci); and
(4) maximum internal inductance, (Li);

(c) the polarity requirements for associated apparatus;

(d) that associated apparatus must not be paralleled unless this is permitted by the associated apparatus Approval;

(e) how to calculate the allowed capacitance and inductance values for field wiring used in the intrinsically safe circuit;

(f) the hazardous locations in which the apparatus may be located.

III DEFINITIONS

For purposes of this standard, the following terms apply:

3.1 ASSOCIATED APPARATUS - Apparatus in which the circuits are not necessarily intrinsically safe themselves, but which affect the energy in the intrinsically safe circuits and are relied upon to maintain intrinsic safety. Associated electrical apparatus may be either:

(a) electrical apparatus that has an alternative type of protection for use in the appropriate potentially flammable atmosphere; or

(b) electrical apparatus not so protected that shall not be used within a potentially flammable atmosphere.

3.2 CLEARANCE DISTANCE - The shortest distance measured in air between conductive parts.

3.3 CONTROL DRAWING - A drawing or other document provided by the manufacturer of the intrinsically safe or associated apparatus that details the allowed interconnections other circuits or apparatus. If the intrinsically safe or associated apparatus is investigated under the entity concept, the control drawing shall include the applicable electrical parameters to permit selection of apparatus for interconnection.

3.4 CREEPAGE DISTANCE - The shortest distance measured over the surface of insulation between conductive parts. Air gaps less than 1 mm (0.04 in.) are not considered to interrupt the surface.

3.5* ENTITY EVALUATION CONCEPT - A method used to determine acceptable combinations of intrinsically safe apparatus and connected associated apparatus that have not been investigated in such combination.

3.6 FAULT - A defect or electrical breakdown of any component, spacing, or insulation which alone or in combination with other faults may adversely affect the electrical or thermal characteristics of the intrinsically safe circuit. If a defect or breakdown leads to defects or breakdowns in other components, the primary and subsequent defects and breakdowns are considered to be a single fault.

3.7 INTERNAL WIRING - Wiring and electrical connections that are made within the apparatus by the manufacturer. Within racks or panels, interconnections between separate pieces of apparatus made in accordance with detailed instructions from the apparatus manufacturer are considered to be internal wiring.

3.8 INTRINSICALLY SAFE APPARATUS - Apparatus in which all the circuits are intrinsically safe.

3.9 INTRINSICALLY SAFE CIRCUIT - A circuit in which any spark or thermal effect, produced either normally or in specified fault conditions, is incapable, under the test conditions prescribed in this standard, of causing ignition of a mixture of flammable or combustible material in air in the mixture's most easily ignited concentration.

3.10 <u>LINEAR OUTPUT ASSOCIATED APPARATUS</u> - Associated apparatus in which the output current is limited by a resistor such that the output voltage-current plot is a straight line drawn between open circuit voltage and short-circuit current.

3.11 <u>MAXIMUM ALLOWED CAPACITANCE</u> - The maximum value of capacitance that may be connected to the intrinsically safe circuit of the associated apparatus.

3.12 <u>MAXIMUM ALLOWED INDUCTANCE</u> - The maximum value of inductance that may be connected to the intrinsically safe circuit of the associated apparatus.

3.13 <u>MAXIMUM INPUT CURRENT</u> - The maximum dc or peak ac current that can be safely applied to the terminals of the intrinsically safe apparatus.

3.14 <u>MAXIMUM INPUT VOLTAGE</u> - The maximum dc or peak ac voltage that can be safely applied to the terminals of an intrinsically safe apparatus.

3.15 <u>MAXIMUM INTERNAL CAPACITANCE</u> - The total unprotected internal capacitance of the intrinsically safe apparatus that must be considered as appearing across the terminals of the intrinsically safe apparatus.

3.16 <u>MAXIMUM INTERNAL INDUCTANCE</u> - The total unprotected internal inductance of the intrinsically safe apparatus that must be considered as appearing across the terminals of the intrinsically safe apparatus.

3.17 <u>MAXIMUM NONHAZARDOUS LOCATION VOLTAGE</u> - The maximum voltage that may be applied to each nonintrinsically safe terminal of the associated apparatus without affecting intrinsic safety.

3.18 <u>MAXIMUM OUTPUT CURRENT</u> - The maximum dc or peak ac current that may be extracted from the intrinsically safe connections of the associated apparatus.

3.19 <u>MAXIMUM OUTPUT VOLTAGE</u> - The maximum dc or peak ac open circuit voltage that can appear at the intrinsically safe connections of the associated apparatus.

3.20 <u>NORMAL OPERATION</u> - Intrinsically safe apparatus or associated apparatus conforming electrically and mechanically with its design specification.

3.21 <u>PROTECTIVE COMPONENT OR ASSEMBLY</u> - A component or assembly which is so unlikely to become defective in a manner that will lower the intrinsic safety of the circuit it may be considered not subject to fault when analysis or tests for intrinsic safety are made, such as the following:

3.21.1 <u>Shunt Diode Barrier Assembly</u> - A fuse-or resistor-protected diode barrier.

3.21.2 <u>Fuse-Protected Shunt Diode Barrier Assembly</u> - A network consisting of a fuse, voltage limiting shunt diodes and a current limiting resistor or other current-limiting components designed to limit current and voltage. The fuse protects the diodes from open circuiting when high fault current flows.

3.21.3 <u>Resistor-Protected Shunt Diode Barrier Assembly</u> - A network that is similar to a fuse-protected shunt diode barrier with the exception that the fuse is replaced by a resistor.

IV EVALUATION OF INTRINSIC SAFETY

4.1 FUNDAMENTAL REQUIREMENTS

4.1.1* Intrinsically safe apparatus, associated apparatus and circuits shall meet the basic requirements specified in Section 4.1.2.

4.1.2 The energy available in the hazardous location shall not be capable of igniting the hazardous atmospheric mixture specified in Section 12.4 due to arcing or temperature during normal operation or under fault conditions.

4.2 NORMAL OPERATION

4.2.1 Normal operation shall include all of the following:

(a) Supply voltage at maximum value. This maximum voltage to be applied for normal operation tests shall be 1.1 times the manufacturer's specified nominal voltage for which the equipment has been designed.

NOTE: DUE TO INTERNATIONAL INTERESTS OF MANUFACTURERS AND AT THEIR SPECIFIC REQUEST, FACTORY MUTUAL WILL EXAMINE EQUIPMENT AT 1.15 TIMES THE MANUFACTURER'S SPECIFIED NOMINAL VOLTAGE.

(b) Environmental conditions within the ratings given for the intrinsically safe apparatus or associated apparatus;

(c) Tolerances of all components in the combination that represents the most unfavorable condition;

(d) Adjustments at the most unfavorable settings;

(e) Opening of any one of the field wires, shorting of any two field wires, or grounding of any one of the field wires of the intrinsically safe circuit being evaluated.

NOTE: OPENING MEANS A COMPLETE SEPARATION OF ALL STRANDS OF THE WIRING.

4.2.2* Normal operation shall include an additional factor for test purposes of 1.5 on energy. Such factors shall be achieved according to the procedures outlined in Section 12.2. Before faults are introduced the apparatus shall be in normal operation as specified in Section 4.2.

NOTE: FACTORS GIVEN IN THIS STANDARD DIFFER FROM THOSE PUBLISHED IN THE CANADIAN AND CENELEC STANDARDS. THIS STANDARD BASES THE 1.5 FACTOR ON ENERGY WHILE OTHER STANDARDS BASE THE 1.5 FACTOR ON CURRENT OR VOLTAGE, WHICH MAY RESULT IN A 2.25 FACTOR ON ENERGY. DUE TO INTERNATIONAL INTERESTS OF MANUFACTURERS AND AT THEIR SPECIFIC REQUEST, FACTORY MUTUAL WILL EXAMINE EQUIPMENT USING THE 1.5 FACTOR ON CURRENT OR VOLTAGE.

4.3 FAULT CONDITIONS

4.3.1 Fault conditions shall include the following:

(a) The most unfavorable single fault and any subsequent related faults, with an additional factor of 1.5 applied to energy;

(b) The most unfavorable combination of two faults and any subsequently related faults, with no additional test factor. Such factors shall be achieved according to the procedures outlined in Section 12.2.

4.3.2 Apparatus in which no fault or only one fault can occur shall be considered acceptable if it complies with

(1) the test requirements for normal operation as defined in Section 4.2 with an additional test factor of 1.5 applied to energy,

(2) the test requirements for any fault that can occur with an additional test factor of 1.5 applied to energy,

and (3) the requirements of this standard.

4.4 EVALUATION PROCEDURE

Circuits shall be evaluated for intrinsic safety as specified in Sections 4.4.1 through 4.4.3.

4.4.1* The circuits shall be analyzed to determine circuit parameters under the normal and fault conditions specified in Sections 4.2 and 4.3. For intrinsically safe apparatus, each possible ignition point where circuit interruption, short circuit, or ground fault may occur shall be considered.

4.4.2 Construction details and temperatures shall be reviewed for compliance with Sections VI and VII. The apparatus shall comply with the applicable test procedures of Section XI.

4.4.3 The possibility of arc ignition under normal and fault conditions shall be determined by either of the following two procedures:

(a) Testing the circuit according to the test requirements of Section XII; or

(b) Comparing the calculated or measured values of current, voltage, and associated inductances and capacitances to the appropriate figures in Appendix B to establish that the current and voltage levels are below the specified values in Section 9.3.

4.5 SOURCES OF IGNITION

In evaluating circuits for intrinsic safety, ignition sources such as the following shall be considered:

(a) Sources of spark ignition:
   (1) Discharge of a capacitive circuit;
   (2) Interruption of an inductive circuit;
   (3) Intermittent making and breaking of a resistive circuit;
   (4) Hot wire fusing.

(b) Sources of thermal ignition:
   (1) Heating of small gage wire strand;
   (2) Glowing of a filament;
   (3) High surface temperature of components.

V ENTITY CONCEPT EVALUATION

5.1* ENTITY EVALUATION

Sections 5.2 through 5.5 are intended for entity evaluations. These requirements may also be used for system evaluations. Only linear output associated apparatus having each output referenced to ground are presently considered in Sections 5.2 through 5.5.

5.2* ASSOCIATED APPARATUS EVALUATION

Associated apparatus shall be evaluated to determine that the circuit connecting to intrinsically safe apparatus is intrinsically safe. Associated apparatus shall comply with Sections 4.2 and 4.3.

5.2.1 The maximum output voltage shall be the highest output voltage from the following:

(a) No faults and the most unfavorable normal operating condition.

(b) The most unfavorable one-fault condition.

(c) The most unfavorable two-fault condition.

5.2.2 The maximum output current shall be the highest short-circuit current obtainable under the conditions specified in Section 5.2.1.

5.2.3 The maximum allowed capacitance is determined by test or by comparison and is the lower value obtained from the following:

(a) The maximum capacitance that does not cause ignition at 1.22 times the maximum output voltage if this voltage was determined with less than two faults.

(b) The maximum capacitance that does not cause ignition at the maximum output voltage if this voltage was determined with two faults.

5.2.4 The maximum allowed inductance is determined by test or by comparison and is the lower value obtained from the following:

(a) The maximum inductance that does not cause ignition at 1.22 times the maximum output current if this current was determined with less than two faults.

(b) The maximum inductance that does not cause ignition at the maximum output current if this current was determined with two faults.

5.3 INTRINSICALLY SAFE APPARATUS EVALUATION

Intrinsically safe apparatus shall be evaluated for the possibility of arc ignition or hot surface ignition using Sections 4.2 and 4.3. The associated apparatus connected to each terminal is determined from the control drawing. The number of faults counted when connecting various allowed combinations of the associated apparatus is described in Section 5.5.

5.3.1 The determination of temperature rise of a component in an entity evaluation shall be made using a power source having parameters that are within the stated entity parameters at a voltage and current that is on the relevant ignition curve.

5.3.2 Capacitive discharge evaluation of the intrinsically safe apparatus is done using the highest specified maximum output voltage from any set of parameters adjusted by the test factor described in Sections 4.2.2 and 4.3, considering current drawn from the source during discharge.

5.3.3 Inductive discharge evaluation of the intrinsically safe apparatus shall be done using an equivalent power source that has parameters within the stated entity parameters at a voltage and current that lie on the relevant ignition curve. The source shall be chosen that causes maximum current flow in the inductor. The current is adjusted using the test factor described in Sections 4.2.2 and 4.3.

5.4* INTRINSICALLY SAFE APPARATUS INDUCTANCE AND CAPACITANCE DETERMINATION

5.4.1 The intrinsically safe apparatus maximum internal capacitance or inductance shall be determined considering both normal and fault conditions by one of the following methods:

(a) Inspection or analytical computation; or

(b) Confirmation of the value by testing in accordance with Section 11.14, if the apparatus manufacturer declares a maximum internal capacitance or maximum internal inductance value; or

(c) Derivation of the value of maximum internal capacitance or maximum internal inductance using the procedure specified in Section 11.14.

5.5 INTRINSICALLY SAFE AND ASSOCIATED APPARATUS SYSTEM EVALUATION

5.5.1 A countable fault is imposed for evaluations based upon the specified maximum output voltage and current ratings. A maximum of one fault is counted even if all associated apparatus common to the system are considered to be at their maximum output voltages and currents.

5.5.2 The shorting of any two associated apparatus outputs or the grounding of any one associated apparatus output shall not be a countable fault. The shorting of each additional associated apparatus output is a countable fault.

5.5.3 If two associated apparatus outputs are shorted and then the connection is grounded, the grounding is a countable fault.

5.5.4 The shorting and grounding specified in Paragraph 5.5.3 shall not be considered if the associated apparatus are connected to separate circuits and the control drawing specifies cables in which shorting is not expected to occur. (Reference ISA RP12.6)

5.5.5 The shorting and grounding specified in Paragraph 5.5.3 shall not be a countable fault if connection is considered because of inadequate spacing within the intrinsically safe apparatus.

5.5.6 The shorting and grounding specified in Paragraph 5.5.3 shall not be a countable fault if connection can be considered through internal resistance within the intrinsically safe apparatus. The evaluation will be done using the most unfavorable internal resistance.

VI CONSTRUCTION REQUIREMENTS

6.1* CREEPAGE AND CLEARANCE DISTANCES

Creepage and clearance distances between uninsulated live parts shall be considered not subject to fault if, taking into consideration likely movement of components, they comply with the values given in Table 6.1, except as noted in Paragraphs 6.1.1 through 6.1.5.

6.1.1 Clearances, creepage distances, and distances through casting compound and insulations that are at least one-third of relevant values, but less than the relevant values specified in Table 6.1 shall be considered connected, if connection results in the most severe condition. Each such connection is to be counted as a fault subject to the requirements in Sections 4.2 and 4.3.

6.1.1.1 If the separation between two conductors is less than one-third that specified in Table 6.1, the conductors are considered connected if connection results in the most severe condition.

6.1.1.2* If more than two conductors are involved and the spacing between adjacent conductors is less than 1/3 the applicable value in Table 6.1, the sum of the individual spacings shall be added until the total spacing equals or exceeds 1/3 the applicable value. Only that number of conductors shall be considered connected. A single fault shall be counted. Within a total dimension equal to the applicable table value, only one such group of conductors shall be considered connected.

6.1.2 Printed Wiring Boards - Printed wiring boards shall comply with the creepage distances specified in Table 6.1. The creepage distances under coating apply to printed wiring boards that are protected by an adherent insulating coating that is:

(a) At least two layers thick of materials (such as solder resist and varnish, or two coats of varnish) that have a minimum dielectric voltage rating of 200 volts per 0.025 mm (0.001 in.) of thickness; or

(b) A single layer not less than 0.7 mm (0.028 in.) thick; or

(c) A single layer, and the printed wiring board complies with the dielectric voltage-withstand test in Section 11.7.3.

6.1.3 The requirements of Paragraph 6.1.1 do not apply where grounded metal (e. g., printed wiring or a partition) separates an intrinsically safe circuit from other circuits and other parts of the same circuit, provided breakdown to ground does not adversely affect intrinsic safety and the grounded conductor can carry the maximum current which would flow under fault conditions.

TABLE 6.1 CLEARANCES, CREEPAGE DISTANCES AND DISTANCES THROUGH CASTING COMPOUND AND INSULATIONS (Notes a, b)

1. Nominal Voltage (Note c) V	2. Creepage Distance mm (in.)	3. Creepage Distance Under Coating mm (in.)	4. Minimum Comparative Tracking Index (Note d)	5. Clearance mm (in.)	6. Distance Through Casting Compound mm (in.)	7. Distance Through Solid Insulation mm (in.)
10	1.5 (0.059)	0.5 (0.020)	90	1.5 (0.059)	0.5 (0.020)	0.5 (0.020)
30	2 (0.079)	0.7 (0.028)	90	2 (0.079)	0.7 (0.028)	0.5 (0.020)
60	3 (0.118)	1 (0.039)	90	3 (0.118)	1 (0.039)	0.5 (0.020)
90	4 (0.157)	1.3 (0.051)	90	4 (0.157)	1.3 (0.051)	0.7 (0.028)
190	8 (0.315)	2.6 (0.102)	175	5 (0.197)	1.7 (0.067)	0.8 (0.031)
375	10 (0.394)	3.3 (0.130)	175	6 (0.236)	2 (0.079)	1 (0.039)
550	15 (0.591)	5 (0.197	175	7 (0.276)	2.4 (0.094)	1.2 (0.047)
750	18 (0.709)	6 (0.236)	175	8 (0.315)	2.7 (0.181)	1.4 (0.055)
1000	25 (0.984)	8.3 (0.327)	175	10 (0.394)	3.3 (0.221)	1.7 (0.067)
1300	36 (1.42)	12 (0.472)	175	14 (0.551)	4.6 (0.308)	2.3 (0.091)
1575	40 (1.58)	13.3 (0.524)	300	16 (0.630)	5.3 (0.355)	2.7 (0.106)
3.3kV	67 (2.64)	23 (0.906)		27 (0.06)	9 (0.602)	4.5 (0.177)
4.7kV	90 (3.54)	30 (2.28)		36 (1.42)	12 (0.803)	6 (0.236)
9.5kV	160 (6.30)	53 (2.09)		60 (2.36)	20 (1.34)	10 (0.394)
15.6kV	240 (9.45)	80 (3.15)		100 (3.94)	33 (2.21)	16.5 (0.65)

a - Creepage distance shall be assessed on the basis of the maximum continual rms voltage. Clearance shall be assessed on the basis of the maximum normal peak voltage.

b - For circuits 1500V or greater and with high power capability the danger due to power arcing in the circuit shall be taken into account.

c - The value of the voltage is the nominal rms voltage for assessing creepage distance and nominal peak voltage for assessing clearance distance, tolerance not considered. The voltages shall be the sum of the normal operating voltages of the circuits being considered, except if the normal operating voltage of one circuit is less than 20 percent of the voltage of the other circuit, the voltage shall be the greater.

d - See Test Method for Comparative Tracking Index of Electrical Insulating Materials, ASTM D 3638-77.

6.1.3.1 A grounded metal partition shall have strength and rigidity so that it is unlikely to be damaged and shall be of sufficient thickness and shall have current-carrying capacity to prevent burn through or loss of ground under fault conditions. A partition at least 0.25 mm (0.01 in.) thick, attached to a rigid, grounded metal portion of the device and meeting the test requirements of Section 11.8 is presumed to meet the requirements of this section.

NOTE: THE 0.25 MM (0.01 IN.) MINIMUM THICKNESS IS JUDGED ADEQUATE FROM THE STANDPOINT OF CURRENT CARRYING CAPACITY.

6.1.4* The requirements of Section 6.1 shall also apply where breakdown between intrinsically safe circuits could increase the energy in the circuit so that it is no longer intrinsically safe.

6.1.5 The clearance between two terminals for connection of field wiring of different intrinsically safe circuits shall be at least 6 mm (0.25 in.) unless no hazard results from connection.

6.2 ENCAPSULATION

6.2.1* If encapsulation is used to separate conductors and components of an intrinsically safe circuit from

(a) nonintrinsically safe circuits,
(b) other intrinsically safe circuits,
(c) other parts of the same circuit, or
(d) grounded metal, the encapsulant shall:

(1) Comply with the Distance-through-Casting-Compound values in line 6 of Table 6.1.

(2) Be adherent to any emerging conductors or components, including printed wiring board substrates,

(3) Have sufficient rigidity to comply with the test requirements specified in Section 11.13 if the encapsulated enclosure is intended for use without additional enclosure, such as a partition device.

(4) Have a temperature rating at least equal to the maximum temperature of any encapsulated component or conductor achieved under conditions after encapsulation, and

(5) Have the comparative tracking index as required in Table 6.1 if any uninsulated conductors or components exit the encapsulant.

6.2.1.1 If encapsulation is used to reduce the risk of ignition of a potentially flammable atmosphere by the following types of components, then the minimum thickness of the encapsulant between such components and the free surface shall be one-half the Distance-through-Casting-compound values in line 6 of Table 6.1, but no less than 1 mm (0.04 in.).

(a) Piezoelectric devices and their connection to any suppression devices.

(b) Energy storage devices and their suppression components where breakage of the connection could occur.

6.2.1.2 If encapsulation is used to reduce surface temperatures, the volume of encapsulant and its minimum thickness over the hot component or conductor shall be at least that necessary to reduce the encapsulant surface temperature to the desired level. The rated operating temperature of the encapsulant shall be at least equal to the hottest surface that it contacts.

6.2.1.3 The free surface of the encapsulant shall comply with the test requirements in Paragraph 11.13.1. If the encapsulant is not protected from shock by another enclosure or partition it shall comply with Paragraph 11.13.2.

6.2.2 The encapsulant shall be identified by generic name, specific type designation, and maximum temperature rating for reporting purposes.

6.3 FIELD WIRING CONNECTIONS

Terminals for intrinsically safe circuits shall be adequately separated from terminals for nonintrinsically safe circuits by one or more of the methods set forth in Paragraphs 6.3.1 through 6.3.3.

6.3.1 Separation may be accomplished by distance. The creepage and clearance distance between adjacent terminals shall be at least 50mm (2 in.). Care shall be exercised in the layout of terminals and in the wiring method used so that contact between circuits is prevented should a wire become dislodged.

NOTE: ADDITIONAL PRECAUTIONS SUCH AS WIRING TIE DOWNS OR SPECIAL WIRING METHODS, MAY BE NECESSARY TO PROVIDE ADEQUATE SEPARATION. THIS IS ESPECIALLY TRUE WHEN TERMINALS ARE ARRANGED ONE ABOVE THE OTHER. IN SUCH CASES, SPACING ALONE WILL NOT USUALLY PROVIDE ADEQUATE SEPARATION.

6.3.2 Separation may be accomplished by locating intrinsically safe and nonintrinsically safe terminals in separate enclosures or by use of either an insulating partition or a grounded metal partition between terminals.

6.3.2.1 Separate enclosures or partitions within common enclosures shall be designed to prevent wiring of an intrinsically safe circuit from contacting the wiring of a nonintrinsically safe circuit, taking into consideration stowage of excess wire in each compartment.

6.3.2.2* Partitions used to separate terminals shall extend to within 1.5 mm (0.06 in.) of enclosure walls to provide adequate separation.

6.3.2.3 Metal partitions shall be grounded and shall possess sufficient strength and rigidity so that they are not likely to be damaged during field wiring (see Paragraph 6.1.3.1).

6.3.2.4 Nonmetallic insulating partitions shall possess sufficient thickness and shall be so supported that they cannot be readily deformed and meet the test requirement of Section 11.8.

6.3.3 Where plugs and receptables are used for external connections, the plugs and receptacles used to connect intrinsically safe circuits shall be noninterchangeable with other plugs and receptacles.

EXCEPTION: THIS REQUIREMENT DOES NOT APPLY TO CIRCUITS OTHER THAN BRANCH CIRCUITS, IF INTERCHANGE DOES NOT AFFECT INTRINSIC SAFETY, OR TO PLUGS AND RECEPTACLES THAT ARE IDENTIFIED SO THAT INTERCHANGE IS UNLIKELY.

6.4 INTERNAL WIRING CONDUCTORS

Internal wiring conductors which are not rigidly supported so as to maintain the spacings specified in Table 6.1 shall be insulated according to Paragraphs 6.4.1 and 6.4.2 and separated according to Paragraph 6.4.3.

6.4.1 Where breakdown may adversely affect intrinsic safety of the same or separate intrinsically safe circuits, each circuit shall be wired with insulated conductors having a grade of insulation capable of withstanding an ac test voltage of 500 volts rms or twice the normal working voltage of the intrinsically safe circuit, whichever is the greater.

EXCEPTION: A DC VOLTAGE MAY BE USED AS DESCRIBED IN SECTION 11.7.1 (a).

6.4.2 Nonintrinsically safe circuits in the same enclosure with intrinsically safe circuits shall be wired with insulated conductors having a grade of insulation capable of withstanding an ac test voltage of 2 U + 1000 volts, with a minimum of 1500 volts rms, where U is the sum of the rms values of the voltages of the intrinsically safe circuit and the nonintrinsically safe circuit (see Section 11.7 for voltage test procedure).

EXCEPTION: A DC VOLTAGE MAY BE USED AS DESCRIBED IN PARAGRAPH 11.7.1 (a).

6.4.3* Segregation of the intrinsically safe and nonintrinsically safe wiring shall be accomplished by enclosing either type of wiring in a grounded shield capable of carrying the fault current which would flow if the nonintrinsically safe circuit were to become connected to the shield.

EXCEPTION: IF THE WIRING OF A NONINTRINSICALLY SAFE CIRCUIT IS RATED AS A NATIONAL ELECTRICAL CODE CLASS 2 OR 3 POWER-LIMITED CIRCUIT, A SHIELD IS NOT REQUIRED. BUT, THE WIRING SHALL BE INSULATED AND SIZED SO THAT OVERLOAD, INCLUDING CONSIDERATION OF FAULTS AND OVERCURRENT PROTECTION, WILL NOT DAMAGE INSULATION TO THE EXTENT THAT THE NONINTRINSICALLY SAFE CIRCUIT BECOMES CONNECTED TO THE INTRINSICALLY SAFE CIRCUIT.

VII PROTECTIVE COMPONENTS

7.1* GENERAL

In evaluating intrinsically safe apparatus and associated apparatus, components complying with the requirements of Paragraph 8.1.1 and the following sections shall be considered not subject to fault.

7.2 TRANSFORMERS

Transformers used as protective components for supplying intrinsically safe circuits shall meet the following construction requirements and the test requirements of Section 11.1.

7.2.1* The winding supplying the intrinsically safe circuit shall be electrically separated from all other windings by one of the following types of construction:

(a) Type 1(a): The windings are side by side on one leg of the core and separated by an insulating partition of not less than 0.71 mm (0.028 in.) thickness. The transformer shall meet the requirements of Section 11.1.2.1.

(b) Type 1(b): The windings are on different legs of the core. The transformer shall meet the requirements of Section 11.1.2.1.

(c) Type 2(a): The windings are wound one over another, with high temperature insulation such as mica, glass fiber, asbestos, layers of polymide film, aromatic polimide paper between the windings, crossover leads and splices supplying the intrinsically safe circuit and all other windings, crossover leads and splices. The transformer shall meet the requirements of Section 11.1.2.2.

NOTE: AN IMBEDDED ONE-TIME THERMAL FUSE MAY BE USED TO PREVENT THE TRANSFORMER FROM IGNITING.

(d) Type 2(b): The input and output windings are wound one over another with a grounded shield of copper foil or an equivalent wire winding between the input winding, all other windings, crossover leads and splices. (see Section 7.2.2).

(e) Type 3: The transformer shall be either Type 1(a), Type 1(b), or Type 2(b) construction, except that the shield of a Type 2(b) construction may be provided with a single lead to the ground connection. No primary fuse is required. The transformer shall meet the requirements of Section 11.1.2.3.

7.2.2 For Type 2(b) construction, the following shall apply:

(a) The thickness of the copper foil or the diameter of the wire shield, as the case may be, shall be so chosen that, in the event of a short circuit between any winding and the shield, the latter will be able to withstand without breakdown the current which flows until the fuse or circuit

breaker functions. The shield shall be considered adequate without testing if it is made of copper foil at least 0.13 mm (0.005 in.) thick.

(b) The shield shall be provided with two independently connected leads to the ground connection, each of which is capable of withstanding without damage the current which flows before the fuse or circuit breaker operates. The shield grounding leads shall be considered adequate without testing if each lead is at least equal in size to the primary leads of the transformer but not less than No. 24 AWG.

(c) A wire-wound shield shall consist of at least two layers of windings.

7.2.3 The input circuit to power supply transformers of Type 1(a) and Type 1(b) constructions or Type 2(b) construction shall include a fuse or circuit breaker in each ungrounded input line. The prospective current rating shall be indicated on the apparatus in a position adjacent to the fuse or on the fuse holder.

7.2.4 The core of a power supply transformer shall be provided with a ground connection, except where grounding is not practicable, as with insulated toroidal core transformers used in dc-to-dc converters.

7.2.5 All transformers shall be impregnated or encapsulated in order to consolidate the windings. Tape-wrapped windings shall-not be considered adequate to consolidate the windings.

7.3 DAMPING WINDING

Damping windings shall be considered not subject to fault if they are of reliable mechanical construction, such as seamless metal tubes, windings of bare wire continuously short-circuited by soldering, or the equivalent.

7.4* CURRENT-LIMITING RESISTORS

Current-limiting resistors meeting the test requirements of Section 11.2 shall be considered not subject to short-circuit fault, if they are of a film type or a wire-wound type with protection to prevent unwinding of the wire in the event of breakage, or of a similar construction whose failure mode increases resistance.

7.5 BLOCKING COMPONENT

7.5.1 Blocking capacitors connected between an intrinsically safe circuit and a nonintrinsically safe circuit shall be considered not subject to fault if two capacitors are connected in series and each capacitor is rated to withstand an ac test voltage of twice the voltage across the capacitors plus 1000 volts rms. They shall be high-reliability types such as hermetically-sealed or ceramic capacitors. Electrolytic or tantalum capacitors shall not be used for this purpose. Failure of a single capacitor

is a countable fault. When analyzing or testing, the capacitance value to be used is the capacitance of one capacitor.

7.5.2 Blocking diodes connected in series with a capacitor so as to block the discharge of capacitive energy shall not be considered subject to fault if they are duplicated.

EXCEPTION: IF THE CAPACITORS ARE CONNECTED IN A SECONDARY CIRCUIT, THEY NEED NOT WITHSTAND THE TEST VOLTAGE SPECIFIED IF THEY ARE EACH RATED FOR THREE TIMES THE FAULT VOLTAGE ACROSS THE ASSEMBLY.

7.6 SHUNT PROTECTIVE COMPONENTS FITTED TO INDUCTIVE ELEMENTS

Shunt protective components, such as diodes and voltage-limiting resistors fitted to inductive elements, shall be considered not subject to fault if they are duplicated. Bridge connected diodes are accepted as duplicated shunt diodes. There shall be no unacceptable increase in energy in the intrinsically safe circuit if one of the components becomes defective. They shall be connected close to the protected component in such a manner that both cannot become disconnected due to a single fault, unless the disconnection of either of the shunt components results in disconnection of the protected component. Breakdown of the protected component to ground shall be considered.

7.7 SHUNT DIODE BARRIER ASSEMBLIES

Shunt diode barrier assemblies shall be considered protective assemblies if they meet the requirements of Paragraphs 7.7.1 through 7.7.8.

EXCEPTION: THE REQUIREMENTS OF SECTION 7.7 MAY NOT APPLY TO SHUNT DIODE BARRIER NETWORKS WHICH ARE AN INTEGRAL PART OF ASSOCIATED APPARATUS.

7.7.1 Barrier component failures shall not increase the energy in the intrinsically safe circuit to an unacceptable level upon application of the maximum voltage to the assembly.

(a) For the purposes of this standard, the maximum voltage of the nonintrinsically safe circuit is assumed to be less than or equal to 250 volts rms unless a higher value is specified. This is the maximum nonhazardous location voltage; application of this voltage is normally considered a fault condition.

7.7.2 Construction of the shunt diode barrier assembly shall comply with the following:

(a) Barrier current-limiting resistors meet the requirements of Section 11.2;

(b) Resistor-protected diodes meet the requirements of Paragraph 11.3.2;

(c) The fuse of a fuse-protected barrier operates (opens, clears) at least 10 times faster than the open circuit time of the barrier, as detailed in Section 11.3.4; or the fuse time-current characteristic shall not permit the steady state or surge current ratings of the protected diode to be exceeded, or each diode used shall be routinely tested with a series of rectangular 50uS current pulses at 60 hertz for 5 seconds. The current shall be that which will flow upon application of 250 volts rms or the specified maximum voltage taking into account all resistance in series with the diode; and

(d) Barrier shunt diodes are duplicated so that the assembly remains effective if one of the diodes open-circuits.

7.7.3 The design of shunt diode barriers shall be such that the assembly can readily be seen to be mounted correctly.

7.7.4 At least one terminal or connection shall be provided on each barrier or barrier assembly for connecting the barrier circuit to ground. The grounding terminal or connection shall be sized to accommodate a No. 12 AWG (3.3 mm^2) minimum grounding conductor. The following constructions or their equivalents are considered suitable:

(a) A No. 8 (4.8mm diameter) wire binding screw that engages the terminal plate by at least two full threads. The terminal plate shall be metal, shall be no less than 1.25 mm (0.05 in.) thick, and shall be provided with upturned lugs or the equivalent to hold the conductor in place.

(b) A pressure-type wire connector complying with the requirements for such connectors. (Soldering lugs, push-in conductors, quick-connects, or similar friction fit connectors are unacceptable.)

(c) Bolting the barrier to a grounding bus.

7.7.5 The ungrounded terminals of the intrinsically safe circuit shall be separated from the ungrounded terminals of the nonintrinsically safe circuit by no less than 50 mm (2.0 in.). They shall be protected to prevent accidental contact with leads connected to other terminals.

7.7.6 The barrier components shall be so mounted and physically arranged to prevent occurrence of a fault which could impair the effective operation of the barrier (e.g., a short circuit of a resistor or fuse; open circuit of a diode).

7.7.7 If components are not encapsulated, the enclosure shall be constructed so as to prevent access to components other than fuses and to protect components.

7.7.8 If it is accessible for replacement, the fuse on a fuse-protected shunt diode barrier shall not be replaceable by one of higher rating.

7.8 OPTICAL ISOLATORS

Optical isolators shall be considered not subject to a short-circuit fault between the input and output circuits if they comply with the requirements in Section 11.5.

VIII OTHER COMPONENT REQUIREMENTS

8.1 DERATING OF DISCRETE COMPONENTS

8.1.1* All components affecting intrinsic safety shall be operated, during normal operation conditions as defined in Paragraph 4.2.1, at not more than 2/3 of their rated current, voltage, or power, as appropriate.

EXCEPTION: TRANSFORMERS NEED NOT COMPLY WITH THIS REQUIREMENT.

8.1.2 Semiconductor devices used as shunt energy limiting components shall not fail in the open condition when subjected to the current which would flow if the semiconductor device short-circuited and the conditions of Section 4.3 are assumed, taking into account overcurrent protection devices [see Section 11.3.4 (b)].

8.2 PLUG-IN BOARDS AND COMPONENTS

Plug-in boards and components shall not be interchangeable with nonidentical boards or components in the same apparatus.

EXCEPTION: WHERE INTRINSIC SAFETY IS NOT AFFECTED FROM INTERCHANGE OR WHERE PLUG-IN BOARDS AND COMPONENTS ARE SO IDENTIFIED THAT INTERCHANGE IS UNLIKELY, NONINTERCHANGEABLE PLUG-IN BOARDS AND COMPONENTS ARE NOT REQUIRED.

8.3* RELAYS

Where intrinsically safe and nonintrinsically safe circuits are connected to the same relay, the creepage and clearance distances shall comply with Section 6.1. The currents and voltages switched by the contacts in the nonintrinsically safe circuits shall not exceed 5 amps and 250 volts, dc or rms, and in addition the product of the current and voltage shall not exceed 100 volt-amperes. If the voltage exceeds 250 volts and the current and volt-amperes do not exceed 10 amperes and 500 volt-amperes, respectively, the creepage and clearance distances shall be twice the applicable values in Table 6.1.

8.3.1 For higher values, the circuits shall be connected to the same relay only if the circuits are additionally separated by a grounded metal partition or an insulating partition. A grounded metal partition shall not be used where breakdown to ground would affect intrinsic safety. A metal partition at least 0.25 mm (0.01 in.) thick, attached to a grounded metal part

of the device, or an insulating partition at least 0.7 mm (0.028 in.) thick is presumed to meet this requirement. A thicker insulating partition may be required to take into account ionization due to operation of the relay.

8.4 CELLS AND BATTERIES

These requirements shall apply to both portable and stationary battery-operated apparatus in which the entire assembly, including batteries, is intended to be used in a Division 1 hazardous location and is not provided with other means of protection, such as an explosionproof or dust-ignitionproof enclosure. These requirements shall apply to both primary (nonrechargeable) and secondary (rechargeable) cells and batteries.

8.4.1 Battery cells shall be of a type from which there can be no spilling of electrolyte, or shall be enclosed to prevent attack by the electrolyte of circuits which affect intrinsic safety. Compartments containing batteries which emit flammable gas shall be ventilated to prevent accumulations of ignitable concentrations.

8.4.1.1 The battery shall be constructed to prevent shorting between internal cells, unless the shorting does not result in an ignition source.

8.4.2 For the purpose of evaluation and test, the battery voltage shall be considered to be the maximum open circuit voltage attainable under normal conditions (i.e., a fresh primary battery or a secondary battery just after full charge). This battery voltage shall not be increased to 110 percent of rated value as is done for rated line voltages.

8.4.3 For the purpose of evaluation and test, the battery short-circuit current shall be the maximum instantaneous current under short-circuit conditions.

8.4.4* When conducting tests which require applying an energy factor of 1.5, in accordance with Section 12.2, one of the following methods, or their equivalents, shall be used:

(a) Additional individual cells identical to the cells used in a multi-cell battery pack shall be added in series or parallel, as appropriate, to yield a simulated battery with at least 1.5 times the energy capacity of the battery used in the apparatus.

(b) The battery voltage or current values, as appropriate, shall be simulated with a suitable power supply, and the value increased so that the energy level is increased by a factor equal to 1.5.

(c) The intended batteries shall be used, either two in series for double voltage or two in parallel for double current, as appropriate, yielding an energy factor greater than 1.5.

NOTE: OPTION (c) MAY BE A MORE STRINGENT TEST THAN OPTIONS (a) AND (b), BUT MAY BE USED IF IT SIMPLIFIES TESTING. FAILURE TO PASS THIS TEST DOES NOT IMPLY THE CIRCUIT IS UNSAFE. INTRINSIC SAFETY MAY BE VERIFIED BY USE OF (a) OR (b).

(d) When batteries are used for spark ignition test, six trials with fresh or full-charged batteries, three for each polarity, shall be conducted.

8.4.5 Battery-operated apparatus in which the battery requires energy-limiting components for intrinsic safety shall either have the energy-limiting components as an integral part of the battery assembly, or use replaceable batteries with the energy-limiting components contained separately within the equipment.

8.4.6 When the energy-limiting components are contained separately within the apparatus, the apparatus shall be constructed as follows:

(a) The energy limiting components shall be located as close to the battery terminals as practical. All of the circuit from the battery to the energy limiting components, except for connection points, shall be insulated and spaced by a minimum clearance distance specified in Table 6.1.

(b) The battery housing or attachment shall be arranged so that batteries can be installed and replaced without short-circuiting the battery output and without applying the battery output to the load side of the energy-limiting components.

(c) For hand-held portable apparatus, such as radio receivers and transceivers, the construction shall prevent the ejection or separation of the batteries from the apparatus even under rough-use conditions, as represented by the drop test described in Section 11.9.

(d) The equipment shall be marked to warn against replacement of the batteries in a hazardous location, as described in Section 13.5.

8.4.7 When an energy-limiting component is necessary and is provided as an integral part of the battery assembly, it shall form a complete replaceable unit with the battery assembly. The assembly shall be such that there shall be no bypassing of the energy-limiting component. The assembly shall be intrinsically safe even under the rough-use conditions, as represented by the drop test described in Section 11.9.

8.4.8* Apparatus or battery packs that are provided with external contacts for recharging the batteries shall be provided with means to prevent the batteries from delivering ignition-capable energy to the contacts when any pair of the contacts is accidentally short-circuited. This may be accomplished by one or more of the following:

(a) Providing blocking diodes or series resistors in the charging circuit. Unless these blocking diodes or resistors are protective components, they shall be considered subject to fault.

(b) Recessing at least one contact of a pair of contacts so that a circular disc probe 1.2 mm (0.047 in.) thick and 18 mm (0.703 in.) in diameter will not touch the contact. In this case, short-circuiting of the pair of charging contacts shall be counted as one fault.

(c) Separately recessing each contact of a pair of contacts so that a circular disc probe as defined in (b) above cannot touch either contact. In this case, short-circuiting of the pair of charging contacts shall be counted as two faults.

(d) Separately recessing each contact of a pair of contacts at least 0.5 mm (0.02 in.) below the plane of the surrounding surface and separating the two contacts such that two circular disc probes as defined in (b) above may touch the contacts but cannot be arranged in any way to simultaneously touch and complete a short circuit between the two contacts. In this case, short-circuiting of the pair of charging contacts shall be counted as one fault.

8.4.8.1 If the charging contacts are not arranged in accordance with Section 8.4.8(b), (c), or (d), short-circuiting of the charging contacts shall be considered a condition of normal operation.

8.4.8.2 If the charging contacts are not separated in accordance with the minimum distances required in Section 6.1, short circuiting of the charging contacts shall be considered a condition of normal operation.

8.5 PORTABLE APPARATUS ENCLOSURES

8.5.1 Exposed external surfaces of the enclosure and parts shall be made of a nonsparking material, such as plastic or brass, unless the part is protected by a recess or a guard.

EXCEPTION: A SURFACE MAY BE OF A SPARKING MATERIAL IF AN INVESTIGATION INDICATES THAT PERCUSSION SPARKS CAPABLE OF IGNITING A FLAMMABLE ATMOSPHERE ARE UNLIKELY.

IX PROCEDURE FOR DETERMINING IGNITION CAPABILITY

9.1* GENERAL

9.1.1 Apparatus may be considered intrinsically safe without spark ignition testing, if the circuits can be readily assessed. The circuits shall be analyzed to determine circuit parameters under the normal and fault conditions specified in Sections 4.2 and 4.3. Each possible ignition point where circuit interruption, short circuit or ground fault is likely to occur in the hazardous location shall be considered.

9.1.2 Circuits that cannot be readily assessed in terms of elementary circuits represented by the ignition curves shown in the figures in Appendix B, circuits in which the current or voltage values exceed those indicated on the curves, and circuits that do not comply with Section 9.3 shall be evaluated by the test procedures in Section XII.

9.1.3 Construction details and temperatures shall be reviewed for compliance with Sections VI, VII, VIII and XIII. The test procedures of Section XI shall be satisfied.

9.2 PROCEDURES

9.2.1 The possibility of spark ignition under normal and fault conditions shall be determined by either of the following two procedures:

(a) Testing the circuit according to the test requirements of Sections X and XII; or

(b) Comparing the calculated or measured values of current, voltage, and associated inductances and capacitances to the appropriate figures in Appendix B to establish that the current and voltage levels are below the specified values in Section 9.3.

9.3 MAXIMUM VOLTAGE AND CURRENT LEVELS

9.3.1 The circuit conditions shall include all normal and fault conditions described in this standard, excluding the factor specified in Section 4.3.

9.3.2 Maximum voltage and current levels (dc or peak ac) in circuits determined to be intrinsically safe by the comparison procedure shall not, exceed the values of Paragraphs 9.3.2.1 and 9.3.2.2 for given circuit constants.

9.3.2.1 For normal or single-fault operation, the current shall not exceed 80 percent of the value determined from Figures B1, B2, B3, B4, B5 and B6. The voltage shall not exceed 80 percent of the value determined from Figures B7 and B8.

9.3.2.2 For two-fault condition, the current shall not exceed 90 percent of the value determined from Figures B1, B2, B3, B4, B5 and B6. The voltage shall not exceed 90 percent of the value determined from Figures B7 and B8.

9.4* MAXIMUM TEMPERATURE

9.4.1 Intrinsically safe apparatus in the hazardous location shall not have, under normal or fault conditions, any surface exposed to flammable or combustible materials that operates at a temperature exceeding the temperature rating marked on the apparatus. If the apparatus is not marked with a temperature rating, the surface temperatur_ shall not exceed 100°C (212°F).

EXCEPTION: RATHER THAN MEASURING TEMPERATURES, THE APPARATUS MAY BE SUBJECTED TO THE TEST SPECIFIED IN SECTION 11.6.

9.4.2* If wiring other than wound coils or transformer wiring of intrinsically safe apparatus is copper and its current is in accordance with the requirements in Table 9.1, or the following equation, temperature tests to determine its maximum surface temperature are not necessary.

$$I = \sqrt{\frac{I_m^2 \, t \, [1 + 0.00393(T - t)]}{T}}$$

In which:

I = current in amperes,
I_m = current at which the wire melts in amperes,
T = temperature at which copper melts, 1083°C,
t = maximum wire temperature, °C.

TABLE 9.1

CURRENTS IN COPPER WIRE (Note a)

Minimum Conductor Size (Note b)					Conductor Current, amperes, for Apparatus Rated T4, T5, or T6		
Diameter		Area		(Wire Size AWG)			
mm	(mils)	mm^2 $x10^{-3}$	$in.^2$ $x10^{-5}$		T4	T5	T6
0.035	1.4	0.962	0.14	-	0.53	0.48	0.43
0.050	2.0	1.96	0.30	44	1.04	0.93	0.84
0.100	3.9	7.85	1.21	38	2.1	1.9	1.7
0.200	7.9	31.4	4.86	32	3.7	3.3	3.0
0.350	13.8	96.2	14.9	27	6.4	5.6	5.0
0.500	19.7	196.	30.4	24	7.7	6.9	6.7

Note a: For conductors on printed wiring boards, the current is 250 percent of that listed in the table. For flexible flat conductors, such as ribbon cable, the tabulated values apply.

Note b: For stranded conductors, the cross sectional area is the sum of the cross sectional areas of each strand of the conductor.

9.4.3* Temperatures higher than that of the marked operating temperature per Section 13.1(d) shall be permitted for small components, for example, transistors or resistors, if it is shown by the test procedures described in Sections 11.6 and 11.11 that the temperature is insufficient to cause ignition of gases or vapors or charring of dusts.

9.5 PROCEDURE FOR TESTING TO DETERMINE IGNITION CAPABILITY

Circuits which cannot be readily assessed in terms of elementary circuits represented by the curves, circuits in which the current or voltage values exceed those indicated on the curves, and circuits which do not comply with Section 9.3 shall be evaluated by the test procedure of Section XII.

X APPARATUS FOR CLASS II AND CLASS III LOCATIONS

10.1 REQUIREMENTS

10.1.1 Intrinsically safe and associated apparatus intended for use in Class II or Class III, Division 1 hazardous locations shall meet all requirements of Sections II through X.

10.2 SPECIFIC REQUIREMENTS FOR INTRINSIC SAFETY

10.2.1 Apparatus and associated wiring that meet the requirements of Sections II through IX of this standard, as applicable, also be shall considered to meet the requirements for Class II and Class III locations, if they comply with Paragraph 10.2.2 and meet the requirements of either Paragraph 10.2.3 or 10.2.4.

10.2.2 The temperature of exposed surfaces of apparatus shall not exceed the following values when tested according to the procedures described in Section 11.11.

Class II, Groups E and F, 200°C (392°F);
Class II, Group G and Class III, 165°C (329°F);
Class II, Carbonaceous Dusts (Group E, F or G) 200°C (392°F).

EXCEPTION: TEMPERATURE EXCURSIONS OF SMALL COMPONENTS UNDER FAULT CONDITIONS MAY EXCEED THESE LIMITS IF IT CAN BE SHOWN BY TEST THAT SUCH HIGHER TEMPERATURES WILL NOT RESULT IN IGNITION OR CHARRING OF THE DUST (SEE SECTION 11.11).

NOTE: "EXPOSED" MEANS EXPOSED TO THE FLAMMABLE OR COMBUSTIBLE MATERIAL OR ATMOSPHERES. PARTS WITHIN A DUST-TIGHT ENCLOSURE ARE NOT CONSIDERED EXPOSED TO THE DUST ATMOSPHERE; THE OUTSIDE SURFACES OF THE ENCLOSURE ARE EXPOSED.

10.2.3* Circuits of intrinsically safe apparatus shall be enclosed in a dust-tight enclosure meeting the requirements of Section 10.3. The apparatus shall also be capable of meeting spark ignition requirements for Class I locations as follows:

Hazardous Location	Applicable Limits
Class II, Group E	Class I, Group C
Class II, Group F or G; Class III	Class I, Group D or Methane

10.2.4* Circuits of intrinsically safe apparatus not enclosed in a dust-tight enclosure meeting the requirements of Section 10.3 shall meet the spark ignition requirements specified in Paragraph 10.2.3. In this case, it shall be assumed that all spacings do not meet the creepage and clearance distance requirements specified in Section 6.1 and that all connections between live or grounded parts and conductors are in the most unfavorable condition. The number of such connections is unlimited.

10.3* DUST-TIGHT ENCLOSURES

10.3.1 For the purposes of this standard, an enclosure is considered suitable if it meets the requirements of Paragraph 10.3.1.1 or 10.3.1.2 or if it complies with the requirements of Section 11.10 or if it is dust-ignitionproof. In addition, a portable apparatus shall be dust-tight after the drop test described in Section 11.9.

10.3.1.1 An enclosure is considered suitable if it conforms to applicable requirements for enclosures for ordinary locations and if it has no openings and if all joints are either threaded with a 3 full-thread minimum engagement or sealed by continuous welding, brazing, soldering or fusion of glass.

10.3.1.2 Parts of apparatus within an enclosure suitable for ordinary locations which are encapsulated to a depth of at least 1 mm (0.04 in.) shall be considered dust-tight.

XI TEST PROCEDURES

11.1 TESTS FOR PROTECTIVE TRANSFORMERS

11.1.1 ROUTINE TESTS

(a) Transformers for direct connection to a supply voltage shall be capable of withstanding the following dielectric voltage withstand test voltages (see Section 11.7)

Where Applied	Test Voltages (rms) (Un = highest rated voltage of any winding)
Between input and output windings	4Un or 2500 V, whichever is the greater
Between all the output windings and the core or screen	2Un or 1000 V, whichever is the greater
Between each winding supplying an intrinsically safe circuit and every other output winding	2Un + 1000 V or 1500 V, whichever is the greater

(b) For transformers not intended for direct connection to a supply voltage, the test voltage between input and output windings shall be reduced to 2Un plus 1000 volts rms or 1500 volts, whichever is greater.

11.1.2 TYPE TESTS

The transformer shall be subjected to the appropriate type test described below, followed by a voltage test of 2Un + 1000 volts rms or 1500 volts, whichever is greater, between any winding used to supply the intrinsically safe system and all other windings (see Section 11.7).

11.1.2.1 Type 1(a) and Type 1(b) Transformers

(a) The secondary winding or windings of the transformer shall be short-circuited or loaded in such a way as to give the highest input current not exceeding 1.5 times the fuse or circuit breaker rating. If 1.5 times the rating of the overcurrent device is not reached, then the secondary winding or windings of the transformer shall be short-circuited or loaded to draw maximum primary current with the primary winding subjected to its worst case rated input voltage. The protective fuse or circuit breaker in the primary circuit shall be bypassed for this test.

(b) The temperature rise of the transformer shall at no point exceed the permissible value for the class of insulation used when in continuous operation for at least 6 hours or up to the moment when the imbedded one-time thermal fuse, if any, functions.

(c) If an output winding is fitted with a current-limiting resistor so arranged that a short circuit cannot occur directly across the winding, the test shall be carried out with the resistor in the circuit.

11.1.2.2 Type 2(a) Transformer

(a) The test shall be carried out by loading the secondary winding (s) to draw maximum primary current with the input winding subjected to its rated input voltage. The input current shall not be limited.

(b) The transformer shall be tested for 6 hours or until failure, whichever occurs first. Either the input winding or the output winding (s) may short-circuit to the core during this test, provided shorting of the output winding (s) to the core does not result in unacceptable energies in the hazardous location.

(c) The transformer shall not ignite during the test.

NOTE: AN IMBEDDED ONE-TIME THERMAL FUSE MAY BE USED TO PREVENT THE TRANSFORMER FROM IGNITING.

11.1.2.3 Type 3 Transformer.

The transformer shall be operated with any or all secondary windings short-circuited, depending on which represents the more severe condition of heating, and with rated voltage applied to the input winding until thermal equilibrium is established. Any thermal fuse or other

current- or temperature-sensitive protective devices shall be short-circuited during this test. The temperature rise of the transformer shall at no point exceed the permissible value for the class of insulation employed.

11.2* CURRENT-LIMITING RESISTORS

Current-limiting resistors shall be evaluated to determine their ability to withstand 1.5 times the maximum resultant fault voltage across the resistor, based on testing at least six samples with the following resistance changes acceptable:

(a) Open circuit
(b) Increase in resistance
(c) Decrease in resistance by not more than 33 percent during the test and no more than 10 percent of its nominal value.

EXCEPTION 1: IF THE RESISTOR IS PROTECTED BY A FUSE, IT IS TO BE TESTED AT (1) A CURRENT OF 1.7 TIMES THE CURRENT RATING OF THE FUSE WITHOUT THE FUSE IN THE CIRCUIT, AND (2) A VOLTAGE 1.5 TIMES THE MAXIMUM FAULT VOLTAGE WITH THE FUSE CONNECTED IN SERIES WITH THE RESISTOR.

EXCEPTION 2: THIS REQUIREMENT DOES NOT APPLY TO RESISTORS THAT ARE OPERATED AT NO MORE THAN TWO-THIRDS OF THEIR POWER RAING DURING BOTH NORMAL AND FAULT CONDITIONS.

11.2.1 The voltage and current shall be monitored during the above test to ascertain resistance change during the test. At the conclusion of the test the resistance shall not have decreased more than 10% of its nominal value.

11.2.2 The test voltage shall be raised from zero to the required value in approximately one minute. The test shall continue until the resistor temperature becomes stable or until it is evident that no further deterioration will occur. Resistors shall not flame during the test.

11.3 SHUNT DIODE PROTECTIVE BARRIER ASSEMBLY TESTS

11.3.1 Barrier current-limiting resistors that affect intrinsic safety shall satisfy the test requirements for current-limiting resistors in Section 11.2.

11.3.2 Resistor-protected barrier diodes shall withstand continuously (i.e., until temperatures have become stable or until it is obvious that no further deterioration will occur) or fail without rendering the barrier ineffective when subjected to 1.5 times the maximum current which will flow continuous through the resistor when up to the maximum safe area voltage is applied to the barrier.

11.3.3 Zener diode maximum voltage shall be the summation of the nominal Zener voltage, plus maximum tolerance of the Zener.

11.3.4 The adequacy of the fuse in preventing open circuiting of the Zener diode shall be determined by one of the following methods:

(a) The barrier assembly fuse shall be substituted by a similar type fuse having an amperage rating 10 times greater. The substituted fuse shall operate (open, clear, fuse) prior to diode failure, upon application of up to the maximum safe area voltage.

(b) A current flow of up to 200 percent of the fuse current rating shall be applied to the barrier assembly, without the fuse, for 10 times longer than the operating time of the fuse. There shall be no diode failure that would render the barrier ineffective. The operating time of the fuse shall be determined by test or taken from the manufacturer's operating time vs. current curve at 200 percent of its current rating.

11.4 TEMPERATURE TESTS

11.4.1 All temperature data shall be referred to a base ambient temperature of 40°C (104°F). Tests to be based on an ambient temperature of 40°C (104°F) may be conducted at any ambient temperature within the range of 20-40°C (68-104°F). The difference between the ambient temperature at which the test was conducted and 40°C (104°F) shall then be added to the temperature measured.

EXCEPTION: TEMPERATURES OTHER THAN THOSE FOR DETERMINING TEMPERATURE MARKING ON COMPONENTS OF ASSOCIATED APPARATUS, SUCH AS PROTECTIVE TRANSFORMERS, SHALL BE REFERRED TO A BASE AMBIENT TEMPERATURE OF 25°C (77°F) OR THE MAXIMUM RATED AMBIENT TEMPERATURE OF THE APPARATUS, WHICHEVER IS HIGHER.

11.4.1.1 Temperatures shall be measured either by thermocouples consisting of wires not larger than No. 24 AWG (0.21 mm^2) or by equivalent means.

EXCEPTION: COIL TEMPERATURES MAY BE DETERMINED BY THE METHOD DESCRIBED IN SECTION 11.4.1.2.

11.4.1.2 A thermocouple shall be used for determining the temperature of a coil or winding of a protective transformer if it can be mounted without removal of encapsulating compound or similar material: (1) on the integrally applied insulation of a coil without a wrap, or (2) on the outer surface of a wrap that is not more than 0.8 mm (0.313 in.) thick and consists of cotton, paper, rayon, or similar material (but not of asbestos or similar thermal insulation). The change-of-resistance method of Section 11.4.1.7 shall be used if the thermocouple measurement cannot be conducted in accordance with the foregoing considerations.

11.4.1.3 Tests shall be conducted until constant temperatures are attained, or until the maximum temperature has been attained, whichever occurs first.

11.4.1.4 A temperature shall be considered to be constant when three successive readings, taken at intervals of 10 percent of the previously elapsed duration of the test (but no less than 5-minute intervals) indicate no change.

11.4.1.5 The thermocouple wire shall conform with the requirements for special thermocouples as listed in the table of limits of error of thermocouples in ANSI C96.1, Temperature Measurement Thermocouples[1].

11.4.1.6 A thermocouple junction and adjacent thermocouple lead wires shall be securely held in good thermal contact with the surface of the material whose temperature is being measured. In most cases, adequate thermal contact will result from securely taping or cementing the thermocouple in place; but if a metal surface is involved, brazing or soldering the thermocouple to the metal may be necessary.

11.4.1.7 The formula for obtaining the temperature rise of a protective transformer winding by the resistance method is as follows (windings shall be at ambient temperature at the start of the test):

$$\Delta t = \frac{R}{r}(k+t_1) - (k+t_2)$$

where Δt = the temperature rise, °C
R = the resistance of the coil at the end of the test, ohms
r = the resistance of the coil at the beginning of the test, ohms
t_1 = the room temperature °C, at the beginning of the test
t_2 = the room temperature °C, at the end of the test
k = 234.5 for copper, 225.0 for aluminum electrical conductor (EC grade).

11.4.2 TRANSISTOR THERMAL RUNAWAY

Transistors shall be tested under the following conditions unless fault analysis indicates such conditions cannot occur.

(a) Six samples of the transistor shall be subjected to this test. The transistor collector and the emitter shall be connected in series with the Thevenin equivalent power source under fault conditions. The polarity shall be such that the emitter is forward biased. A variable resistor shall be connected between the transistor base and collector. The resistance shall be slowly decreased until a thermal-runaway condition occurs or until the resistance is reduced to zero. The test shall be continued under these conditions until maximum temperatures are attained.

[1] Available from the American National Standards Institute, 1430 Broadway, New York NY 10018

(b) The test described in 11.4.2 (a) shall be conducted with the transistor heat sink in place if the transistor and heat sink are assembled together in such a manner that the assembly will remain intact, giving consideration to the method of assembly.

11.4.3 SMALL GAGE WIRE

If the temperature of the wire exceeds the marked operating temperature of the equipment or 100°C (212°F) for equipment not having a marked operating temperature, the wire shall pass the test requirements of Section 11.6.

11.5 OPTICAL ISOLATOR TESTS

11.5.1 An optical isolator in a secondary circuit shall withstand the test voltage specified in Paragraph 11.1.1 (b).

11.5.2 An optical isolator shall be capable of withstanding a 4000 volt rms test voltage initially and 1000 volts plus twice the highest rated voltage of the circuit or 1500 volts, whichever is greater, after the limited short circuit test procedure described in Paragraph 11.5.3. The test voltage shall be applied between the intrinsically safe circuit and the nonintrinsically safe circuit. Six samples shall be used for each test. See items (a), (b), and (c) in Paragraphs 11.7.1 and 11.7.2.

11.5.3 With regard to Paragraph 11.5.2, the open circuit voltage of the test circuit shall be the nominal maximum rated nonhazardous location voltage, for example, 120 or 240 volts. The available instantaneous short-circuit current capacity of the test circuit shall be at least 200 amperes. The test circuit shall be connected to the optical isolator so that the test current flows through the nonintrinsically safe circuit terminals of the optical isolator. Protective components or fuses shall be permitted in the circuit for the test.

11.6 SMALL COMPONENT THERMAL IGNITION TEST

Small components which either exceed the marked operating temperature of equipment intended for use in Class I locations or exceed 100°C (212°F) for equipment not required to be marked with an operating temperature shall not cause ignition of the flammable mixture used when tested according to Paragraphs 11.6.1 through 11.6.5.

11.6.1 The flammable mixture used shall be diethyl ether for apparatus marked T4, or:

(a) Classified in NFPA 497M-1986, in the Class I hazardous location group(s) for which the equipment is intended;

(b) The most easily ignitable concentration of the flammable material having an autoignition temperature equal to or less than the marked operating temperature of the equipment.

EXCEPTION: IF THE EQUIPMENT IS NOT MARKED WITH AN OPERATING TEMPERATURE, THE FLAMMABLE MATERIAL USED SHALL BE THAT WHICH HAS THE LOWEST AUTOIGNITION TEMPERATURE OF ANY MATERIAL IN ANY HAZARDOUS LOCATION GROUP FOR WHICH THE EQUIPMENT IS INTENDED.

11.6.2 The component shall be mounted in the apparatus as intended, or the component may be tested in the mixture to determine the temperature at which ignition occurs. The flammable mixture shall be introduced into the apparatus enclosure so as to assure contact between the mixture and the surface of the component being tested. If this is impractical, such a condition shall be simulated so as to assure representative test results, taking into consideration other parts of the apparatus in the vicinity of the component being tested which could affect the temperature of the mixture and the flow of the mixture around the component due to ventilation and thermal effects.

11.6.3 The test shall be conducted under the normal or fault condition specified in Section IV, whichever produces the maximum surface temperatures on the component.

11.6.4* The test shall also be conducted under the normal or fault condition which produces the maximum release of thermal energy whenever such condition produces a maximum surface temperature that both exceeds the marked operating temperature and is lower than that produced in Section 11.6.3.

11.6.5 The tests specified in Sections 11.6.3 and 11.6.4 shall continue until thermal equilibrium of the component under test and surrounding parts is attained or until the temperature of the component under test drops to a value equal to the marked operating temperature as a result of failure of the component, whichever occurs first. If failure of the component terminates the test, five additional samples shall be tested to assure that ignition will not occur. If no ignition occurs, the mixture shall be ignited by other means to verify presence of a flammable mixture.

11.7 DIELECTRIC VOLTAGE WITHSTAND TEST

11.7.1 The following test method shall be used:

(a) The test shall be made with alternating voltage of substantially sinusoidal wave form at a frequency between 48 Hz and 62 Hz. Alternately the test is conducted using a dc voltage having no more than 3% peak to peak ripple at a level of 1.414 times the specified ac voltage.

(b) The supply shall have sufficient volt-ampere capacity to maintain the test voltage, taking into account any leakage current which may occur.

(c) The voltage shall be increased steadily to the specified value in a period not less than 10 seconds and then maintained for at least 60 seconds.

(d) For routine tests, the test voltage may be increased 20 percent and applied for not less than one (1) second.

11.7.2 Test results are acceptable if there is no breakdown of the insulation between the test points.

11.7.3 Representative circuits on printed wiring boards coated with a single layer of adherent insulating coating that is less than 0.7 mm (0.028 in.) thick shall be subjected to a dielectric voltage withstand test. See Paragraphs 11.7.1 and 11.7.2 for the test method. The test voltage shall be based on the operating voltages of the circuits being considered in accordance with Note c to Table 6.1 and the values specified in Table 11.7.3.

TABLE 11.7.3

COATED BOARD DIELECTRIC VOLTAGE WITHSTAND TEST VALUES

Circuit Operating Voltage, V		Withstand Test, kV, rms
Peak	rms	
10	7.07	1.39
30	21.2	1.68
60	42.4	2.21
90	63.6	2.68
190	134.4	3.11
375	265.2	3.51
550	388.9	3.89
750	530.3	4.26
1000	707.1	4.95
1300	919.2	6.59

11.8 MECHANICAL TEST

Partitions shall withstand a force of 30 newtons (6.75 lbf). The force shall be applied using a rigid test rod having a 6 mm (0.25 in.) diameter ball at the point of contact. The force shall be applied at the approximate center of the partition for 10 seconds. There shall be no deformation of the partition that would defeat its purpose.

11.9 DROP TEST

Portable apparatus shall be subjected to the following drop test. Intrinsic safety shall not be affected.

(a) The apparatus shall be dropped at least six times, but not more than once on one surface, edge or corner, from a height of 1 meter (39.4 in.) onto a smooth horizontal concrete floor.

(b) If appropriate, a nonrestrictive guide may be used to assure a free-fall drop on the surface to be tested.

11.10 DUST-TIGHT ENCLOSURE TEST

For the purpose of this standard, an enclosure is considered suitable for Class II and III locations if it meets the requirements of Factory Mutual Approval Standard Dust-Ignitionproof Electrical Equipment, Class No. 3616.

11.11 DUST BLANKETING TEMPERATURE TEST

11.11.1 The apparatus shall be mounted in its normal position and shall be covered with the dust mixture specified in Section 11.11.1 A. until no more will stay on the enclosure or component (see Section 10.2.2 note) or to a depth of 12 mm (0.48 in.) whichever is less.

A. The dust used shall be one of the following:

- Wheat or corn dust (or a mixture of both);
- Type 1, General Purpose Portland Cement; or
- Aluminum oxide.

The dust shall be fine enough to pass through a 100-mesh screen. Alternatively, magnesium dust may be used for Group E.

11.11.2 The apparatus shall be operated under fault conditions appropriate to the device until all temperatures become constant (see Section 10.2).

11.11.3 The temperature of surfaces exposed to dust shall not exceed the values given in Section 10.2.2. Temperatures shall be based on temperature rise above ambient in the test chamber and 40°C (104°F).

11.11.4 Excursions of temperatures of small components above the final constant temperature are permitted if the test dust is grain dust.

11.11.5 There shall be no evidence of charring or ignition of grain dust.

11.12 LAMP BREAKAGE TEST

11.12.1 The heated filament of a tungsten-filament lamp shall not ignite a surrounding explosive mixture when the glass envelope is broken.

11.12.2 The lamp shall be mounted in a test chamber connected to a normal (no fault) power supply. The chamber shall be filled with an explosive mixture specified in Section 12.4 in accordance with applicable fault procedures in Section 4.3. The lamp envelope shall be broken quickly

and completely (not just cracked) while the lamp is immersed in the mixture to expose the glowing filament to the explosive mixture. The filament shall not be broken by the breakage of the envelope. Six samples shall be tested.

11.13 ENCAPSULATION TESTS

11.13.1 FORCE TEST

An encapsulant shall withstand a force of 30 newtons (6.74 lbf) applied using the flat end of a 6 mm (0.24 in.) diameter solid test rod. The force shall be applied for at least 10 seconds in a direction perpendicular to the surface of the encapsulant. The encapsulant may transiently move during the test, but shall not permanently deform or be damaged in a way that impairs the protection provided.

11.13.2 IMPACT TEST

Encapsulant that is not protected from shock by another enclosure or partition shall also be subjected to an impact test of 2 joules (1.48 ft-lbf). The encapsulant may transiently move during the test, but shall not permanently deform or be damaged in a way that impairs the protection provided.

11.13.2.1 The impact shall be applied by a 0.25 kg (0.55 lb) test mass having a hardened steel impact head 25 mm (0.98 in.) diameter falling through a vertical distance of 0.8 meters (2.62 ft).

11.13.2.2 The apparatus shall be mounted on a steel base having a mass of at least 20 kg (44 lb) or shall be mounted on a steel base rigidly fixed to or inserted in the floor. The direction of the impact shall be normal to flat surfaces being tested, or normal to a tangent to the surface if the surface is not flat.

11.13.3 SOLVENT VAPOR EXPOSURE

An encapsulant shall be constructed of materials suitable for the intended environment including consideration for atmospheric contaminants and for corrosive compounds. There shall be no deterioration that impairs the protection provided when tested according to Approval Standard 3600, Section 5.2.

11.14 INTERNAL CAPACITANCE OR INDUCTANCE TEST

11.14.1 This section applies to apparatus to be investigated in accordance with items (b) or (c) in Section 5.4. The effective capacitance or inductance of the intrinsically safe apparatus shall be determined by the change in capacitance or inductance required to just prevent ignition using the spark ignition test apparatus and methods described in Section XII.

11.14.2 A variable capacitor shall be tested in accordance with Section 12.6. The capacitor shall be adjusted until ignition just does not occur. The test source voltage shall be 1.22 times the maximum input voltage. The value of the capacitor (C1 in Section 11.14.5) shall be recorded.

11.14.3 The intrinsically safe apparatus is then to be connected in parallel with the variable capacitor using whatever terminals on the intrinsically safe apparatus are relevant. In some cases, the test may have to be repeated using a different set of terminals.

11.14.4 The variable capacitor and intrinsically safe apparatus combination shall be tested in accordance with Section 12.6. The variable capacitor shall again be adjusted until ignition just does not occur. The value of the variable capacitor (C2 in Section 11.14.5) shall again be recorded.

11.14.5 The maximum internal intrinsically safe apparatus capacitance, Ci, for those terminals is the difference between the two recorded capacitance values as follows: $Ci = C1-C2$. A negative number is assumed to be zero.

11.14.6 The procedure described in Paragraphs 11.14.2 through 11.14.5 shall also be used to determine the effective inductance. In this case, the terminals of the intrinsically safe apparatus shall be placed in series with a 95 millihenry inductor. The power source shall be 24 volts dc open circuit. However, the source voltage and inductance may be altered to improve sensitivity for circuits that operate on currents higher than 100 milliamperes. The current shall be varied with noninductive series resistance until ignition just does not occur. The difference in currents can then be related to the effective inductance utilizing the appropriate curve in Appendix B.

XII SPARK IGNITION TEST

12.1 GENERAL REQUIREMENTS

12.1.1 All circuits requiring spark ignition testing shall be tested to ensure that they are incapable of causing ignition under the conditions specified in Section IV, taking into account the appropriate gas group(s) specified in Section 12.4 (see also Paragraph 10.2.3).

12.1.2 Normal and fault conditions shall be simulated during the test. Factors shall be added as described in Section 12.2. Specialized test apparatus as described in Section 12.4 shall be used rather than the contacts used in the field. The test apparatus contacts shall be operated in a chamber filled with the test gas mixture and verified in accordance with Section 12.5.

12.2 TEST FACTORS

An additional factor shall be used when applicable. Where an

additional factor of 1.5 is required by Section IV, it may be achieved by the methods given in Paragraphs 12.2.1, 12.2.2, or 12.2.3 below.

NOTE: DUE TO INTERNATIONAL INTERESTS OF MANUFACTURERS AND AT THEIR SPECIFIC REQUEST FACTORY MUTUAL WILL EXAMINE EQUIPMENT USING THE 1.5 FACTOR ON CURRENT OR VOLTAGE.

12.2.1 Resistive circuits having an inductance less than 5 uH: the energy shall be increased by a factor of 1.5 in order of preference as follows:

(a) Decreasing the values of limiting resistance;

(b) Increasing the line voltage;

(c) Increasing other supply voltages;

(d) Increasing the setting of voltage limiting devices.

12.2.2 Inductive circuits: the energy shall be increased by a factor of 1.5 by first reducing the values of limiting resistance as much as practical, then by increasing the voltage.

12.2.3 Capacitive circuits: the energy shall be increased by a factor of 1.5 by increasing the voltage by a factor of 1.22.

12.3* TEST APPARATUS

12.3.1 The spark test apparatus shall consist of an explosion chamber of about 250 cubic centimeters (15.25 cu. in.) volume, in which circuit-making-and-breaking sparks can be produced in the presence of the prescribed test gas.

12.3.2* Components of the contact arrangement are a cadmium disc with 2 slots and 4 tungsten wires of 0.2 mm (0.008 in.) diameter, which slide over the disc. The free length of the tungsten wires shall be 11 mm (0.44 in.). The driving spindle, to which the tungsten wires are attached, shall make 80 revolutions a minute. The spindle on which the cadmium disc is mounted shall revolve in the opposite direction. The ratio of the speeds of the driving spindle to the disc spindle shall be 50 to 12. The spindles shall be insulated from one another and from the housing. See Figure 12.3.2. The explosion chamber shall withstand pressures up to 1470 kPa (213.2 psi) or be provided with suitable pressure relief. When cadmium, zinc, or magnesium will not be present, the cadmium disc may be replaced by a tin disc.

12.4 GAS MIXTURES

12.4.1 For Group D, the test mixture shall be 5.25 ±0.25 percent propane in air.

12.4.2 For Group C, the test mixture shall be 7.8 ±0.5 percent ethylene in air.

12.4.3 For Groups A and B, the test mixture shall be 21 ±2 percent hydrogen in air.

12.4.4 For Class II, Groups E, F, and G, the test mixture shall be 5.25 ±0.25 percent propane in air or 8.3 ±0.3 percent methane in air.

12.4.5 Intrinsically safe apparatus that is intended for use in a particular gas or vapor and that is be marked accordingly shall be tested in the most easily ignited concentration of that gas or vapor in air.

12.5 VERIFICATION OF SPARK TEST APPARATUS

12.5.1 The sensitivity of the spark test apparatus shall be checked before and after each test series carried out in accordance with Section 12.4. For this purpose, the test apparatus shall be operated in a 24 volt dc circuit containing a 0.095 H air-core coil. The currents in these circuits shall be set at the values given in Tables 12.5.1(a) and 12.5.1(b) for the appropriate group, and the spark test apparatus shall comply with both the "must ignite" and "must not ignite" specifications in the tables.

NOTE: THE PURITY OF COMMERCIALLY AVAILABLE GASES AND VAPORS IS NORMALLY ADEQUATE FOR THESE TESTS, BUT THOSE OF PURITY LESS THAN 95 PERCENT SHOULD NOT BE USED. THE EFFECT OF NORMAL VARIATIONS IN LABORATORY TEMPERATURE AND PRESSURE AND OF THE HUMIDITY OF THE AIR IN THE GAS MIXTURE IS ALSO LIKELY TO BE SMALL. ANY SIGNIFICANT EFFECTS OF THESE VARIABLES WILL BECOME APPARENT DURING THE ROUTINE VERIFICATION OF THE SPARK TEST APPARATUS.

TABLE 12.5.1(a)
CURRENT IN CALIBRATION CIRCUIT
FOR CADMIUM DISC

Group	Inductive Circuit Currents, mA	
	Must Not Ignite	Must Ignite
A & B	25.5	30
C	49	65
D	71	100
*		110

* For tests using Methane, see 12.4.4.

TABLE 12.5.1(b)
CURRENT IN CALIBRATION CIRCUIT
FOR TIN DISC

Group	Inductive Circuit Currents, mA	
	Must Not Ignite	Must Ignite
A & B	41	50
C	77	90
D	98	110

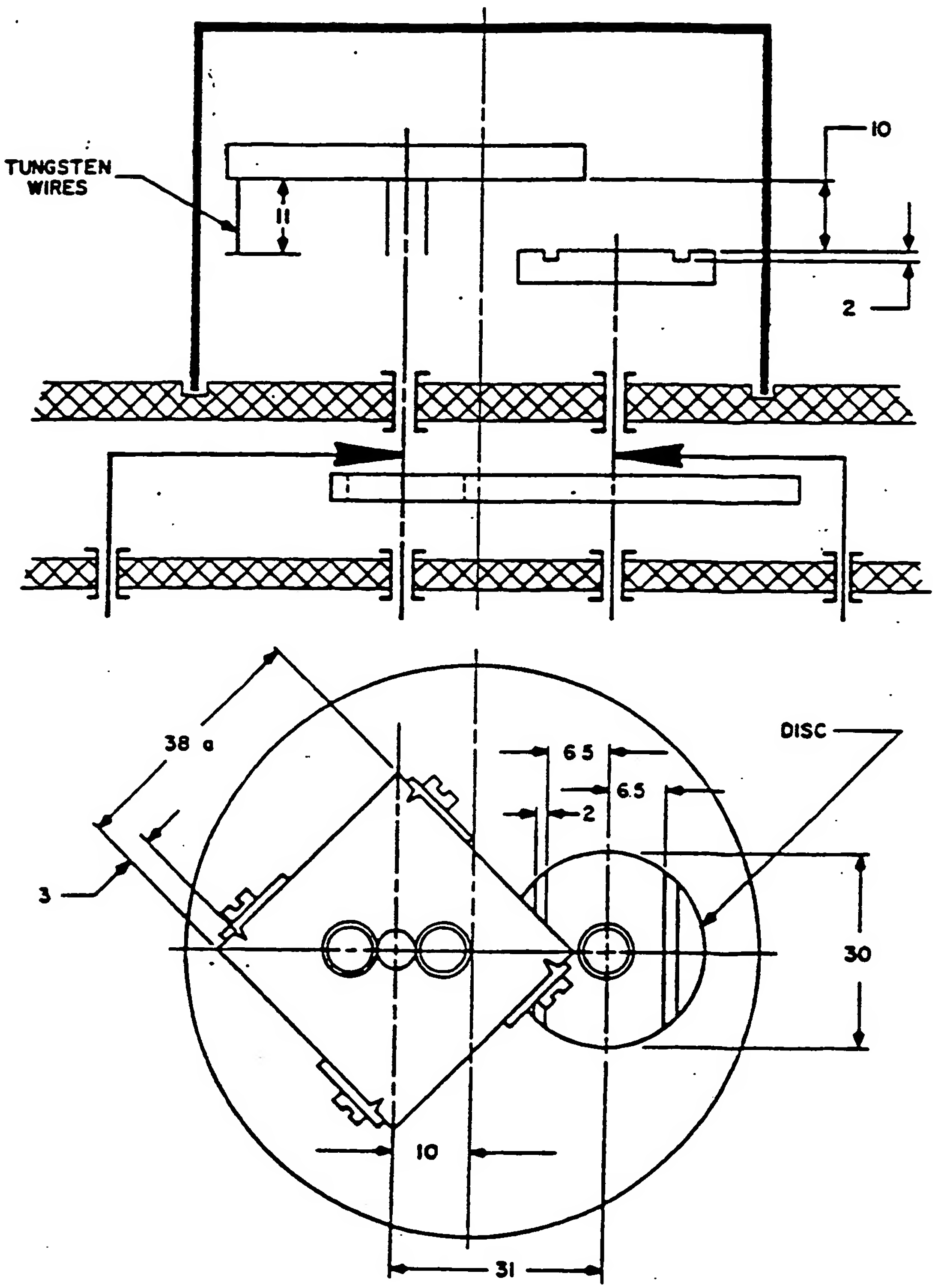


Figure 12.3.2 Test Apparatus for Evaluating Intrinsically Safe Circuits. Measurements are in millimeters.

12.5.2 The spark test apparatus shall be run for 400 revolutions (5 minutes) of the tungsten wire-holder with the holder at positive polarity and shall be considered to be satisfactory only if at least one ignition of the test gas occurs.

12.6 TEST PROCEDURE

12.6.1 After verification, the spark test apparatus shall be connected in each circuit requiring test as determined in accordance with Section 4.4.

12.6.2 Each circuit shall be tested for the following number of revolutions of the tungsten wire holder in the spark test apparatus:

(a) For dc circuits, not less than 400 revolutions (5 minutes), 200 revolutions at each polarity;

(b) For ac circuits, not less than 1,000 revolutions (12.5 minutes).

12.6.3 After each circuit test, verification of the spark test apparatus shall be repeated as follows: If the circuit test resulted in ignition, the "must not ignite" verification in Section 12.5 shall be repeated; if the circuit test did not result in ignition, the "must ignite" verification in Section 12.5 shall be repeated. If the verification does not comply with the applicable portion of Section 12.5, the spark test on the circuit under investigation shall be considered invalid.

XIII MARKING

13.1 INTRINSICALLY SAFE APPARATUS

The minimum marking of intrinsically safe apparatus shall be readily visible by the user and include the following:

(a) Manufacturer's name or trademark, address, and type or model designation;

(b) Intrinsically safe for hazardous location class, division and group;

(c) Reference to associated apparatus or a control drawing number, except apparatus not intended to be connected to the apparatus or circuits.

(d) Operating temperature or temperature identification number based on operation at 40°C (104°F) ambient temperature [See Approval Standard 3600, Section 4.1.1 (c)].

EXCEPTION 1: APPARATUS HAVING AN OPERATING TEMPERATURE NO GREATER THAN 100°C (212°F) NEED NOT HAVE A MARKED OPERATING TEMPERATURE OR TEMPERATURE IDENTIFICATION NUMBER.

EXCEPTION 2: TEMPERATURE MARKING MAY BE LOWER THAN THE MINIMUM OBSERVED FOR SMALL COMPONENTS MEETING THE REQUIREMENTS OF SECTIONS 9.4 AND 11.6.

(e) The Factory Mutual Approval Mark.

EXCEPTION: INTRINSICALLY SAFE APPARATUS SIZE NOT PERMITTING MINIMUM MARKING SHALL HAVE THE FACTORY MUTUAL APPROVAL MARK AND A MANUFACTURER'S IDENTIFYING MARK.

13.2 ASSOCIATED APPARATUS

The minimum marking of associated apparatus shall be readily visible by the user and include the following:

(a) Manufacturer's name or trademark, address, and type or model designation;

(b) Intrinsically safe terminals (e.g. terminals, outputs, inputs) for hazardous location class, division, and group.

(c) Control drawing number, except for apparatus not intended to be connected to other apparatus or circuits.

(d) For shunt diode and similar barrier protective assemblies, which are intended for field or panel installation, the maximum nonhazardous location voltage [see Paragraph 7.7.1(a)].

(e) The Factory Mutual Approval Mark

EXCEPTION: ASSOCIATED APPARATUS SIZE NOT PERMITTING MINIMUM MARKING SHALL HAVE THE FACTORY MUTUAL APPROVAL MARK AND A MANUFACTURER'S IDENTIFYING MARK.

13.3 INTRINSICALLY SAFE AND ASSOCIATED APPARATUS OPTIONAL MARKINGS

In addition to the marking specified in Sections 13.1 and 13.2, the marking shall, where practical, include the following. If this information is not on the equipment, it shall be included in the accompanying literature.

(a) Where repair is possible, a warning label worded "WARNING - SUBSTITUTION OF COMPONENTS MAY IMPAIR INTRINSIC SAFETY"; and

(b) Any other necessary information, in particular, an indication of any type of protection and its characteristics.

(c) A reference to accompanying literature that provides special installation, maintenance, or operating instructions. If this information is not on the apparatus, it shall be included or referenced on the control drawing.

13.4 MARKING INTRINSICALLY SAFE CONNECTIONS

Terminals, terminal boxes, and plugs and receptacles for connection to intrinsically safe circuits shall be clearly identified and clearly distinguishable. Where color only is used to satisfy this requirement, it shall be bright blue.

13.5 MARKING BATTERY-POWERED APPARATUS

13.5.1 When the batteries used are not intrinsically safe, the apparatus shall be marked with a warning such as: "WARNING - BATTERIES MUST BE CHANGED IN A NONHAZARDOUS LOCATION ONLY."

13.5.2 Battery-powered apparatus shall be marked with a caution statement to identify the manufacturer and part number of the battery.

13.6* ENTITY CONCEPT MARKINGS

13.6.1 In order to facilitate interconnection of intrinsically safe apparatus and associated apparatus Approved under the entity evaluation concept, the following marking should be required on the product:

(a) For associated apparatus supplying the power to intrinsically safe apparatus and wiring, the following in addition to Section 13.2 should be included in the marking:

(1) Maximum output voltage, (Voc);
(2) Maximum output current (Isc);
(3) Maximum allowed capacitance, (Ca); and
(4) Maximum allowed inductance, (La).

(b) For intrinsically safe apparatus receiving power from associated apparatus the following in addition to Section 13.1 should be included in the marking:

(1) Maximum input voltage, (Vmax);
(2) Maximum input current (Imax);
(3) Maximum internal capacitance, (Ci); and
(4) Maximum internal inductance, (Li).

(c) The values of Paragraphs 13.6.1 (a) and (b) shall be those values determined by the procedure in Appendix C.

13.7 FACTORY MUTUAL APPROVAL MARK

The Approval Mark shall be a reproduction of the artwork in Appendix D.

13.8 MARKING PERMANENCY

See Approval Standard 3600, Section 4.1.2.

13.9 MARKING ABBREVIATIONS

The following are acceptable for marking brevity:

Class:	- CL
Division	- DIV
Group:	- GP
Hazardous Location:	- HAZ. LOC.
Intrinsically Safe:	- INT. SAFE or IS

13.10 MARKING DRAWINGS

13.1.1 The manufacturer's drawing delineating marking shall be reviewed prior to apparatus Approval and all subsequent revisions shall be reviewed by Factory Mutual.

13.10.2 A reference to accompanying literature, that provides special installation, maintenance, or operating instructions. If this information is not on the apparatus, it shall be included or referenced on the control drawing.

XIV MANUFACTURING AND FIELD INSTALLATION REQUIREMENTS

14.1 DEMONSTRATED QC PROGRAM

14.1.1 A Quality Control Program is required to assure that each subsequent device produced by the manufacturer shall present the same quality and reliability as the specific samples examined. Design quality, conformance to design, and performance are the areas of primary concern.

Design quality is determined during the examination and tests.

Conformance to design is verified by control of quality in the following areas:

- Existence of corporate quality control guidelines
- Incoming inspection and test
- In-Process inspection and test
- Final inspection and test
- Equipment calibration
- Drawing and change control
- Packaging and shipping

Quality of performance is determined by field performance and by re-examination and test.

14.1.2 The manufacturer shall establish a system of product configuration control to prevent unauthorized changes, including, as appropriate:

- Engineering drawings
- Engineering change requests
- Engineering orders
- Change notices

These shall be executed in conformance with a written policy and detailed procedures. Records of all revisions to all Approved products shall be kept.

14.1.3 The manufacturer shall assign an appropriate person or group to be responsible to obtain Factory Mutual authorization of all changes applicable to Approved products. FMRC Form 797, Approved Product Revision Report or Address/Contact Change Notice, is provided to notify Factory Mutual of pending changes.

14.2 FACILITIES AND PROCEDURES AUDIT (F&PA)

14.2.1 An inspection of the product manufacturing facility shall be part of the Approval investigation. Its purpose shall be to determine that equipment, procedures, and the manufacturer's controls are properly maintained to produce a product of the same quality as initially tested.

14.2.2 Unannounced follow-up inspections shall be conducted to assure continued quality control and product uniformity.

ADDITIONAL INFORMATION

Appendix A is not part of this standard, but is included for informational purposes only.

A2.1 Division 1 hazardous locations, as defined in NFPA 70-1987, National Electrical Code, include locations defined in many other countries and by the International Electrotechnical Commission (IEC) as Zone 0. Zone 0 locations are hazardous because of the presence of flammable or combustible materials within the flammable range all or a large percentage of the time. In those nations which recognize Zone 0 as well as Zone 1, in which hazardous material may be present in normal operation for a lesser percentage of the time, two sets of requirements for intrinsically safe systems are recognized. For Zone 0 application, systems must not be capable of causing ignition after consideration of two faults, as in this document. For systems designed to be installed only in Zone 1 locations, only one fault must be considered. Zone 0 and Zone 1 are not recognized in NFPA 70-1987, National Electrical Code.

A2.2 The experimental data on which the requirements of this document are based were determined under normal laboratory atmospheric conditions. Ignition parameters are not easy to extrapolate from normal laboratory conditions to other conditions (such as might exist in process vessels) without careful engineering consideration. Increasing the initial temperature of a flammable or combustible mixture will decrease the amount of energy required to cause ignition so that, at the autoignition temperature of a gas or vapor, the electrical energy required for ignition will approach zero. The nature of the energy variation between these limits is not well documented. Temperature variations can also change the concentrations of flammable materials in the mixture.

Oxygen enrichment decreases the energy necessary for ignition. The minimum ignition energy of mixtures of flammable materials with oxygen may be one-hundredth of that required for the same material mixed with air.

As a general rule, the minimum ignition energy is inversely proportional to pressure squared. When examining a situation where the gas mixture is not at atmospheric pressure, one must consider whether a flammable mixture exists under higher pressure conditions. When the mixture is at high pressure many flammable materials will condense.

A2.4 Factory Mutual Approval Standard No. 3810 "Electrical and Electronic Test, Measuring and Process Control Equipment" specifies compliance with the following American National Standards:

ANSI Designation	Title
ANSI/ISA S82.01-1987	"Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment - General Requirements"
ANSI/ISA S82.02-1987	"Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment - Electrical and Electronic Test and Measuring Equipment"
ANSI/ISA S82.03-1987	"Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment - Electrical and Electronic Process Test, Measuring, Controlling and Related Equipment"

NOTE: THESE STANDARDS ARE AVAILABLE FROM:

The Instrument Society of America
67 Alexander Drive
Research Triangle Park
North Carolina 27709

In the event that the category of equipment is not covered under the scope of ANSI/ISA S82.01, 82.02 or 82.03 and another ANSI standard exists for the equipment category, that standard shall be used.

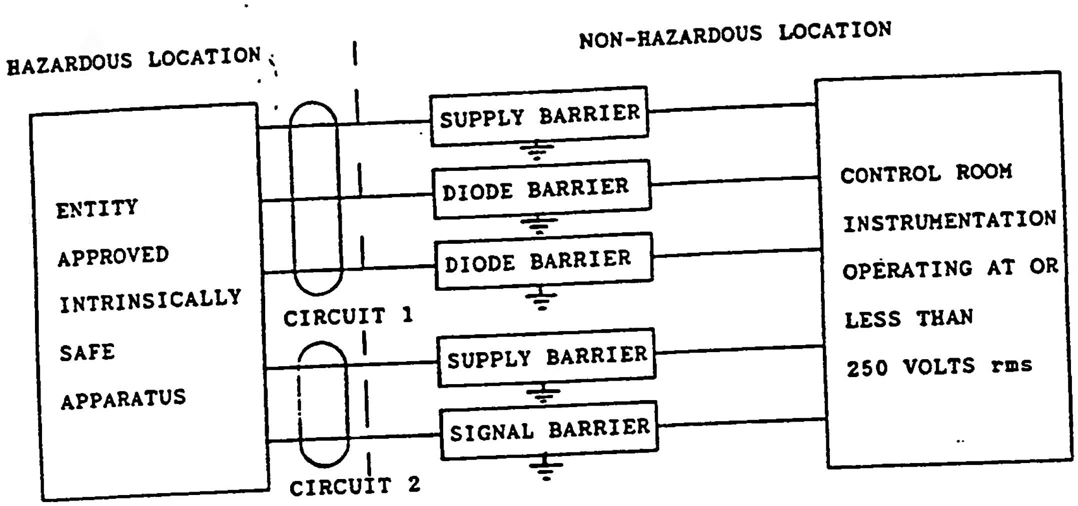
A2.5 Figure A2.5 is an example of information to be shown on the control drawing. The specified set(s) of parameters are evaluated to ascertain that permitted fault connections of these associated apparatus do not create an ignition capable circuit.

The phrase "normally provides power" means that if the wire to the intrinsically safe apparatus were disconnected, grounding of the wire would cause a spark when the unspecified apparatus is operating as intended. For example, if the associated apparatus is connected to a 24 volt power supply, grounding would cause a spark.

Application of maximum allowable cable capacitance and inductance. When cable parameters are known, the system designer adds the parameters for lengths of cable to be used to the known parameters of the intrinsically safe apparatus. The sums are then compared to the allowable parameters marked on the associated apparatus. If the electrical parameters of the cable are unknown, the following values may be used:

Capacitance - 60 pF/ft
Inductance - 0.20 μH/ft

Based on a survey of manufacturer's data, few cables exceed either of these values.



Notes on Intrinsically Safe Apparatus

1. Circuit 1 and Circuit 2 must be in separate cables or in one cable which has suitable insulation. Refer to Instrument Society of America Recommended Practice ISA RP 12.6 for installing intrinsically safe loops.

Notes on Associated Apparatus

1. May be in a Division 2 locations if so Approved.
2. Cable capacitance and inductance plus the I.S. apparatus unprotected capacitance (Ci) and inductance (Li) must not exceed the allowed capacitance (Ca) and inductance (La) indicated on the associated apparatus.
3. Must be installed in accordance with the manufacturer's guidelines.
4. Associated apparatus must not be connected in parallel unless approved in such combination.
5. All associated apparatus must be of the same polarity.
6. Associated apparatus must have a Voc and Isc not exceeding the Vmax and Imax shown for each type of associated apparatus in the following table.

Class I,II,III Haz. Location Group	Supply Barrier Vmax (V)	Supply Barrier Imax (mA)	Signal Barrier Vmax (V)s)	Signal Barrier Imax (mA)	Diode Barrier Vmax (V)	Diode Barrier Imax (mA)
A,B,C,D,E,F,G	40	150	13	350	40	0
C,D,E,F,G	35	250	13	350	40	0

Figure A2.5. Example Control Drawing

A3.5 The concept of intrinsic safety depends upon associated apparatus limiting energy to a safe level and then interconnecting only those intrinsically safe apparatus which can not store ignition capable amounts of energy. Traditionally, the examination was based on a combination of associated and intrinsically safe apparatus, which were specified by manufacturer's name and type number. This traditional method created a serious problem for manufacturers and users in that only a small portion of possible equipment combinations were ever evaluated by a third party testing lab. A need existed for a convenient method of determining if apparatus of different manufacturers could be interconnected in intrinsically safe loops. The entity concept was developed to satisfy this need.

A4.2.2 It is recognized that the real margin of safety lies in the use of a test apparatus more sensitive than any probable accident condition, the use of the ideal gas mixture in testing, and the extreme improbability of the coincidence of multiple-circuit faults and external wiring failure at the precise time and place that the ideal gas mixture is present.

A4.4.1 For evaluation of intrinsic safety, the relevant circuit parameters are open-circuit voltage, short-circuit current, capacitance and inductance.

A5.1 The entity concept allows for associated apparatus and intrinsically safe apparatus to be evaluated as separate entities. Apparatus evaluated under the entity concept must have a control drawing that specifies the allowed apparatus and the terminals to which they may be connected. The description is not done in terms of vendor name and type number, but rather by the specified maximum voltage and the specified maximum current. The values specified may be combinations of voltage and current that are above the ignition curve.

A5.2 At this time, the ignition curves only apply to associated apparatus with linear outputs. Entity listing of intrinsically safe apparatus using associated apparatus with nonlinear outputs must be the subject of special investigation. The control drawing must be explicit in identifying those parameters applicable to linear output associated apparatus and those applicable to nonlinear associated apparatus.

The evaluation does not consider possible summing of maximum output voltages which might be possible with associated apparatus having two or more outputs where the voltage is limited between the outputs, but not between the outputs and ground.

A5.4 Intrinsically safe apparatus may have a large amount of capacitance mounted inside. A method of protection is to add series resistance. High capacitance with series resistance may be equivalent to a much lower capacitance (but not zero) with no series resistance. The test in 11.14 is intended to determine the equivalence. If the equivalent capacitance must be determined, it may require several spark ignition tests. The manufacturer may

greatly reduce these tests by specifying what the equivalent capacitance might be. Then, after determination of C1 (see Section 11.14.2) one test is run with the intrinsically safe apparatus connected in parallel with an adjustable capacitor set to a value of (C1-Ci). If no ignition occurs, then the value is acceptable and must be marked on the unit as the internal capacitance. It is possible that the value specified by the manufacturer may be considerably higher than the actual equivalent capacitance which would have been determined from the more exhaustive series of tests.

A6.1 The values in Table 6.1 represent assumptions of accumulation of dust, dirt, and films and are quite conservative. There is a substantial body of opinion that industrial apparatus of the type which can be made intrinsically safe will remain so with spacings even below those given in Table 6.1.

A6.1.1.2 For example, consider a 14 pin component that has a spacing between pins of 0.3 mm and voltage under 10 volts. Any three pins may be shorted together with one fault counted. Within any group of 6 pins only one such set of three pins will be shorted. In this case two such groups of three can be shorted and counted as two faults.

A6.1.4 Where two identical intrinsically safe circuits are derived from the same power supply, lack of appropriate creepage and clearances may result in an increase in the energy in the circuit so that it is no longer intrinsically safe. If the external circuits are assumed to be shorted or grounded, twice the current will flow into the ground connection, exceeding the current for which the circuit is designed. If the two intrinsically safe circuits are derived from different power supplies, a connection of the two circuits, as would be assumed if the creepage and clearance distances are not in accordance with the requirements of Table 6.1 will, in almost all cases, subject one of the circuits to voltages or currents higher than the design value.

A6.2.1 ADHERENCE - The removal of creepage requirements from encapsulated components is based upon the removal of the possibility of contamination. The measurement of comparative tracking index (CTI) is, in effect, a measurement of the degree of contamination needed to cause breakdown of a separation between conducting parts. The following facts emerge from this basic consideration:

(a) If all electrical parts and substrates are totally enclosed in that nothing emerges from the encapsulation, then there is no risk of contamination and hence breakdown due to that source cannot occur.

(b) If any part of the circuit, such as a bare or insulated conductor or component or the substrate of a printed wiring board, exits the encapsulant then unless the encapsulant adheres at the interface then contamination can enter at that interface and cause breakdown.

The above facts indicate that what is required is to maintain a seal at the interfaces described and to do this it is necessary that the encapsulant adhere at those points.

TEMPERATURE - All encapsulants have a maximum temperature above which they may lose or change their specified properties. Such changes may cause cracking or decomposition which could result in surfaces hotter than the outside surface of the encapsulant being exposed to a potentially explosive atmosphere.

For this reason, it is necessary to confirm that the encapsulant does not exceed its maximum rated operating temperature when the circuits enclosed are operated under fault conditions. In achieving this it should be noted that components which are encapsulated may be hotter or colder than they would be in free air depending on the thermal conductivity of the encapsulant.

A6.3.2.2 No specific design requirements are stated in support of this general requirement because several attempts have failed to yield a satisfactory rationalization of the differing requirements of a compartment which might be only a few inches on a side and a large compartment such as a relay rack or cubicle. In a small enclosure, it might be a reasonable requirement, for example, that a partition must extend within approximately 1 wire diameter of the enclosure wall. In the case of a cubicle, or other large enclosure, such a requirement would impose unnecessary restrictions on tolerances and manufacture of the separating partition with no appropriate increase in safety.

To a considerable extent the level of safety achieved in a large enclosure is dependent upon the location of connections, the volume set aside for wire storage, and other factors which affect the likelihood of wire being pushed through any aperture between the enclosure wall and the partition. If the wire used for connections is small and the volume available for storage is small a requirement that the partition extend within 1.5 mm of the enclosure wall might be reasonable. If the stowage volume is larger and connection points are some distance from the gap between the partition and the enclosure wall, even a 1-inch or larger gap between the partition and the enclosure wall might provide adequate separation. In general, if the partition provides 50 mm separation between intrinsically safe and non-intrinsically safe terminals, measured in any direction, or if the partition is within 1.5 mm of the walls, separation would be considered adequate.

A6.4.3 For Class 2 circuits, Article 725 of NFPA 70-1984, National Electrical Code, specifies only that insulation be suitable for the particular application. For Class 3 circuits, minimum requirements for insulation thickness are specified, primarily to ensure protection against electric shock. Should a fault occur in a Class 2 or Class 3 circuit, heat might be generated in the wiring to damage the insulation. Though this event is unlikely to result in a fire hazard in ordinary applications, it is necessary that it be given due consideration in intrinsically safe systems.

A7.1 Requirements for components given in this Section are not mandatory requirements for the construction of all intrinsically safe apparatus and associated apparatus. Protective components are not required if the circuit is still incapable of causing ignition after two components are assumed to have failed.

A7.2.1 The insulation thickness specified for Type 1(a) transformers is less than presently interpreted as being required by European certifying authorities, in addition, although no thickness specification is given for Type 2(a) transformers, interpretations by certifying bodies in other countries has required 1 mm of insulation between the winding(s) supplying intrinsically safe circuits and other windings. Type 3 construction is permitted based on the assumption that the transformer design is such that no thermal stress on the insulation occurs when windings are short-circuited due to, for example, the rating of insulation, winding impedances, and saturation level. (See Section 11.1.2.3.)

The type 2(a) and type 3 transformer construction do not include a requirement for fuses or circuit breakers in the primary wiring. This requirement differs from the Canadian and European standards which require a fuse in each ungrounded line voltage input. In these two excepted cases the addition of a fuse or circuit breaker does nothing to enhance intrinsic safety as in 2(a) construction, the transformer is not proven to breakdown primary to secondary without benefit of a fuse, and in type 3 construction there is no significant heating of the transformer leading to breakdown.

A7.4 Resistors used as protective component limiting capacitive energy in intrinsically safe apparatus may be evaluated at 200% of the minimum input current to determine if they can withstand up to 1.5 times the maximum resultant fault voltage.

A8.1.1 This differs from some European requirements which specify operation at not more than two-thirds of rated current under fault conditions.

A8.3 The limitations in this standard on current, voltage, and voltamperes are in agreement with values accepted or proposed in European standards. The limits were established because of a concern that, in an enclosed volume, as in relay enclosures, ionization at arcing relay contacts in the non-intrinsically safe circuit might cause breakdown of the intrinsically safe circuit, even if creepage and clearance distance requirements in Table 6.1 are met.

The 5 ampere, 250 volt, 100 volt-ampere figures represent, in the absence of a technical rationale for establishing limit values, levels at which adverse conduction is presumed to be highly improbable, but which would encompass most common uses of relays. For high levels, additional precautions, as given in 8.3.1, are required.

A8.4.4 It may be determined by analysis or test that the battery or cells have such low energy available that no further protection is required for intrinsic safety. Such apparatus does not require charging-contact protection, output current-limiting, or any other energy-limiting components.

A8.4.8 The circular disc probe described in item (b) is representative of a dime, the smallest US coin. This probe dimension was selected on the assumption that the apparatus might be carried in the user's pocket.

A9.1 The voltage and current levels specified for judging the intrinsic safety of apparatus by analysis alone after two faults are lower than those required when the apparatus is tested. A decrease in energy is imposed to allow for errors in determining circuit constants. For example, the measured inductance of many components depends on the method used. The appropriate inductance value to be used in ignition calculations may not be self-evident. The safety of systems which are analyzed is also ensured by the nature of the conditions under which the reference curves were determined. These curves were determined with the IEC test apparatus in which the contact geometry is optimized to encourage ignition at low currents.

Additionally, the ignition data represents the minimum levels of current which will cause ignition of the flammable material in its most easily ignitible concentration more than once in a thousand attempts.

A9.4 It is a fundamental requirement of intrinsically safe apparatus that it shall be incapable of causing ignition either by arcing or thermal effects. If the temperature of any part of the apparatus exposed to the flammable or combustible material is below the autoignition temperature (AIT) of the material, the apparatus is safe with regard to thermal ignition. There is much data in the literature, however, which shows that surfaces of limited extent and small components may safely exceed the AIT without causing ignition. Safety in Mines Research Establishment (SMRE) in England has shown that large resistors may exceed the AIT by 100-300°C (212-572°F), depending upon the gas and vapor involved, without causing ignition. Smaller components and wires must reach even higher temperature (see A9.4.3).

Reliably designed electronic equipment does not normally have component or wire surface temperatures above the AIT when operating normally. When one considers the effects of two faults, it is frequently the case that resistors or semiconductors may be exposed to voltages and currents considerably higher than they carry in normal operations. It is under fault conditions that concern for hot wire or hot surface ignition, and the need for careful analysis, is greatest.

For intrinsically safe equipment in Class II and III hazardous locations, the greatest danger is ignition of a dust layer. For classified dusts, if the surface temperature of the apparatus under normal conditions does not exceed 120°C (248°F), and under fault conditions does not exceed 165°C (329°F), it may be assumed that the device will not cause ignition as a result of high surface temperature.

There is considerably less information in the literature regarding the ability of small components to rise above the 120°C (248°F) or 165°C (329°F) value without causing ignition, but on theoretical grounds, supported by some experimental evidence, it can be concluded that even in Class II and III locations, the temperatures of small components may rise above the temperature stated. Inability of the component to cause ignition must, of course, be demonstrated by test of the actual components under fault conditions.

A9.4.2 If I_m is unknown, it may be determined by test. The current through the wire should be increased in stages to allow thermal equilibrium before incrementing the current to the next higher stage.

A9.4.3 The ignition temperature of gases and vapors which is listed in reference documents such as NFPA 497M is determined under conditions where a significant volume of gas is at the same temperature. When ignition is attempted with a small component, convection effects and partial oxidation at the surface of the component decrease the rate of heat transfer to the gas. Therefore the component must be at a temperature much higher than the quoted ignition temperature to ignite the flammable mixture. Typical transistors, resistors, and similar small components must have a surface temperature of 220-300°C to ignite diethyl ether whose ignition temperature is 160°C. Similar values have been measured in ignition tests of carbon disulfide whose ignition temperature is 100°C.

A temperature classification of T4 may be assessed where components comply with the requirements of Table A9.4.3.

Table A9.4.3
Assessment for T4 Classification According to Component Size and Ambient Temperature

Total Surface Area excluding Lead Wires	Requirement for T4 Classification
$<20mm^2$	Surface temperature ≤275°C
$\geq 20mm^2$ $\leq 10cm^2$	Not exceeding 1.3 W* or a surface temperature ≤200°C

* Reduce to 1.2 W with a 60°C ambient temperature or 1.0 W with 80°C ambient temperature.

A10.2.3 Although the ignition energy of dusts, either in clouds or layers, is in general much higher than for gases and vapors under similar test conditions, there are indications in Bureau of Mines Report R16516, Explosibility of Metal Powders, that layers of dusts, especially fine magnesium powders, can be ignited by amounts of energy comparable to those for gases and vapors. For this reason, it is felt prudent at this time to impose somewhat greater restrictions on Group E dusts than on Group F and G dusts.

A10.2.4 If an enclosure is not dust-tight the possibility of reduction of spacings by conductive dusts must be considered. Therefore, the most hazardous combination of such reduction of spacings is specified. Typically, this would necessitate the device being evaluated with all capacitors considered to be paralleled, all inductors connected in series, and the effective resistive load on circuits supplying the device to the loads which produce the highest surface temperatures (maximum power transfer) and a short circuit (maximum ignition current).

Although Group G dusts are usually considered nonconductive, the same requirement is applied. It was not felt necessary to specify a different requirement and to sort out the possibility of degradation of dust characteristics over a long period of time in the presence of moisture, other conductive agents, etc. It is recognized that this requirement is excessive for Group G applications, especially where there is no possibility of the dust being wet and contaminated with conductive materials.

A10.3 The dust-tight enclosures defined by these requirements are intended to prevent potentially hazardous accumulation of dusts. These requirements are less stringent than requirements for enclosures for nonintrinsically safe equipment in Class II, Division 1 locations. Those latter enclosures must have more stringent requirements because the apparatus inside may be ignition capable by arc or temperature in normal operation. Such is not the case with intrinsically safe apparatus.

A11.2 Properly derated film and wirewound resistors have been found suitable as protective components for use within intrinsically safe apparatus and associated apparatus.

A11.6.4 The combined requirement of Sections 11.6.3 and 11.6.4 is intended to ensure investigation of not only the highest temperature (Section 11.6.3) which may exist for only a short time, but a lower long term temperature.

A12.3 The apparatus is that described in IEC Publication 79-3. (See Figure C1). At currents greater than 3A, arc ignition is aided by heating of the tungsten wires so that the igniting currents determined by test are too low. For testing at higher current levels, heavier wires or a different type of apparatus may be needed. (Copper wires 0.25 mm (0.01 in.) in diameter have been used.)

The apparatus is suitable for testing circuits up to 300 volts. For tests of capacitive circuits, a modified apparatus (e.g., one with two or more of the wires removed) may be needed to allow adequate charging time.

A12.3.2 Where field wiring is a part of the intrinsically safe circuit, it is normally assumed that cadmium or zinc is present, due to common use of these materials for corrosion protection.

A13.6 One of the serious problems which has faced both manufacturers and users in applying the intrinsic safety concept has been the inability to interconnect apparatus of different manufacturers and be assured that the combination is still intrinsically safe. The marking provides a convenient way to assess the compatibility of apparatus of different manufacturers with respect to intrinsic safety. The criteria for the comparison is that the voltage and current which a load device can receive and remain intrinsically safe, assuming the fault conditions, must be equal to or greater than the voltage and current levels which can be delivered by a source device, assuming fault conditions and factors on energy. In addition, the maximum unprotected capacitance and inductance of the load, including interconnecting wiring, must be equal to or less than the capacitance and inductance which can be safely driven by the source device with the combination remaining intrinsically safe. If these two criteria are met, then two devices which have not been evaluated as a combination may be connected and intrinsic safety ensured.

IGNITION VOLTAGE AND CURRENT CURVES

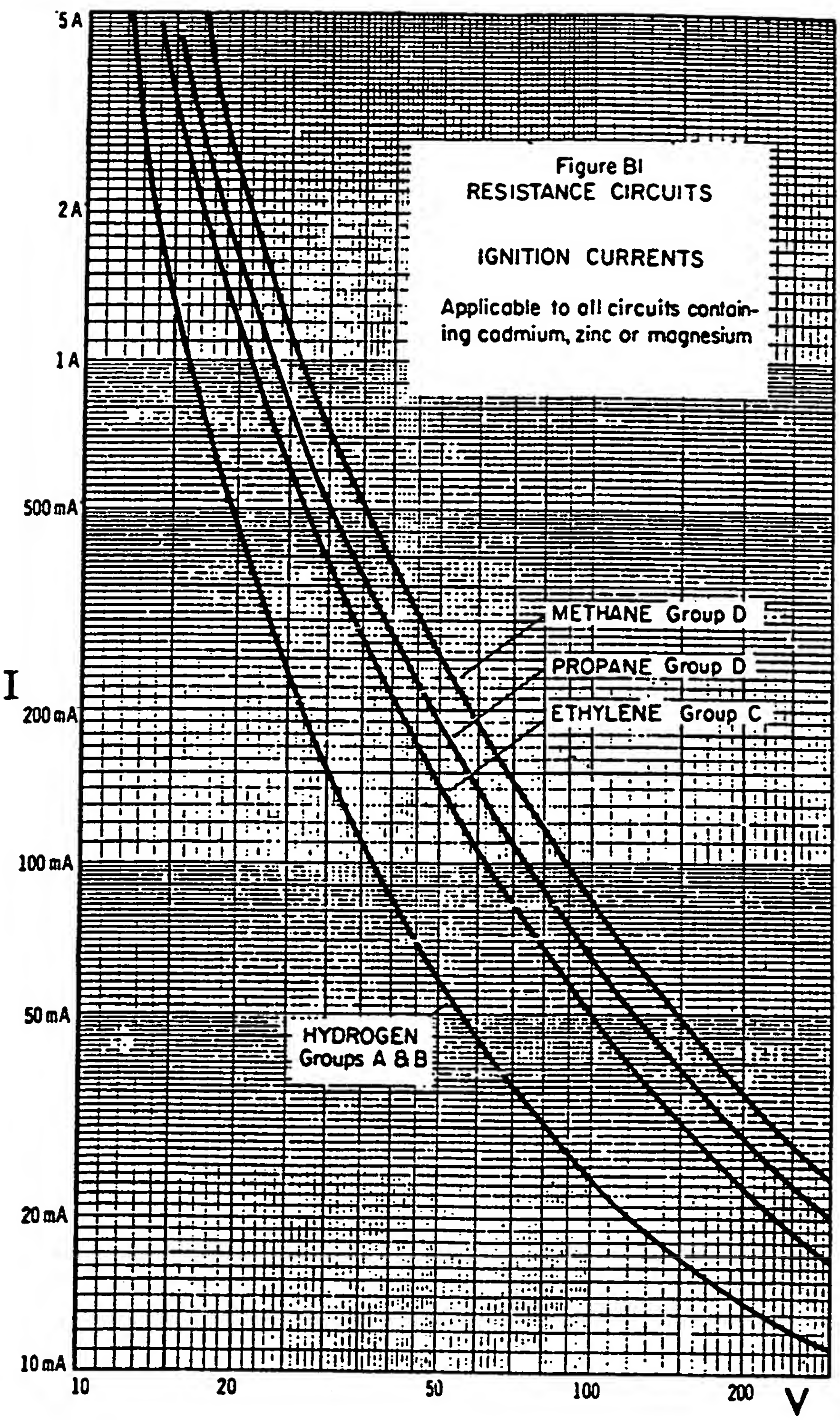
B1 All figures, except Figures B5 and B6 are reprinted from Certification Standard SFA 3012, 1972 edition, with permission of the Health and Safety Executive, British Approvals Service for Electrical Equipment in Flammable Atmospheres. Figures B5 and B6 are from "Some Aspects of the Design of Intrinsically Safe Circuits," Research Report 256, 1968, by D. W. Widginton, Safety in Mines Research Establishment, Sheffield, England.

B2 Resistance Circuits - Figures B1 and B2 apply to resistance circuits only and show the combinations of voltage and current which will ignite gas and vapors in air for Groups A, B, C and D. These figures apply only to circuits whose output voltage-current characteristic is a straight line drawn between open circuit voltage and short-circuit current (i.e., no voltage or current regulators).

B3 Resistance-Inductance Circuits - Figures B3 and B4 apply to resistance inductance circuits and show the combination of inductance and current at 24 volts which will ignite gases or vapors in air for Groups A, B, C and D. Figures B5 and B6 apply to resistance-inductance circuits and show the combination of inductance and current at specific voltages which will ignite gases or vapors in Group B and methane, respectively.

B4 Resistance-Capacitance Circuits - Figures B7 and B8 apply to resistance capacitance circuits and show the combination of capacitance, voltage, and resistance which will ignite gases or vapors of methane and hydrogen respectively. These curves represent capacitor discharge only. They do not include the additional current which may be available from the power supply.

RESISTANCE CIRCUITS
IGNITION CURRENTS



RESISTANCE CIRCUITS
IGNITION CURRENTS

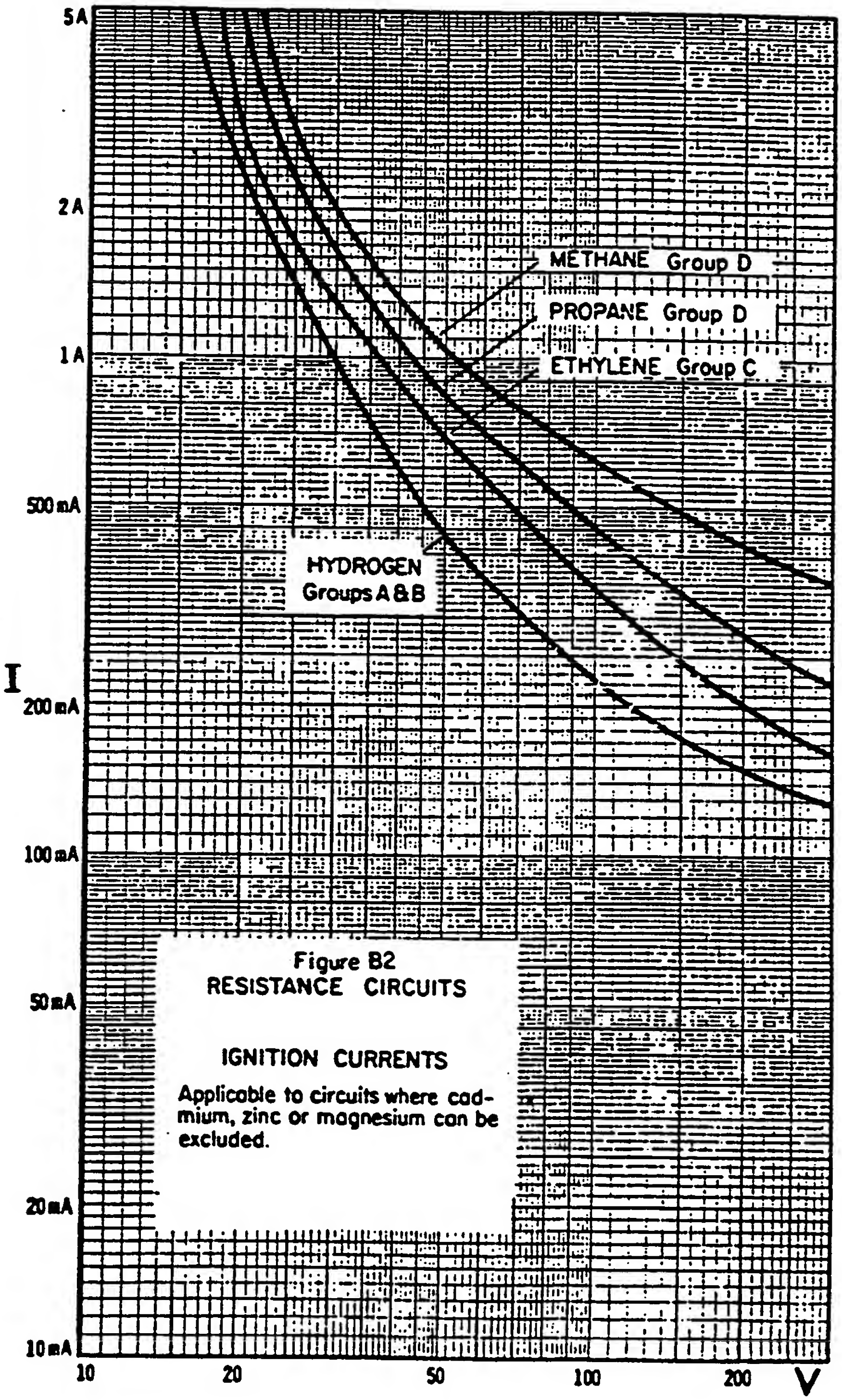
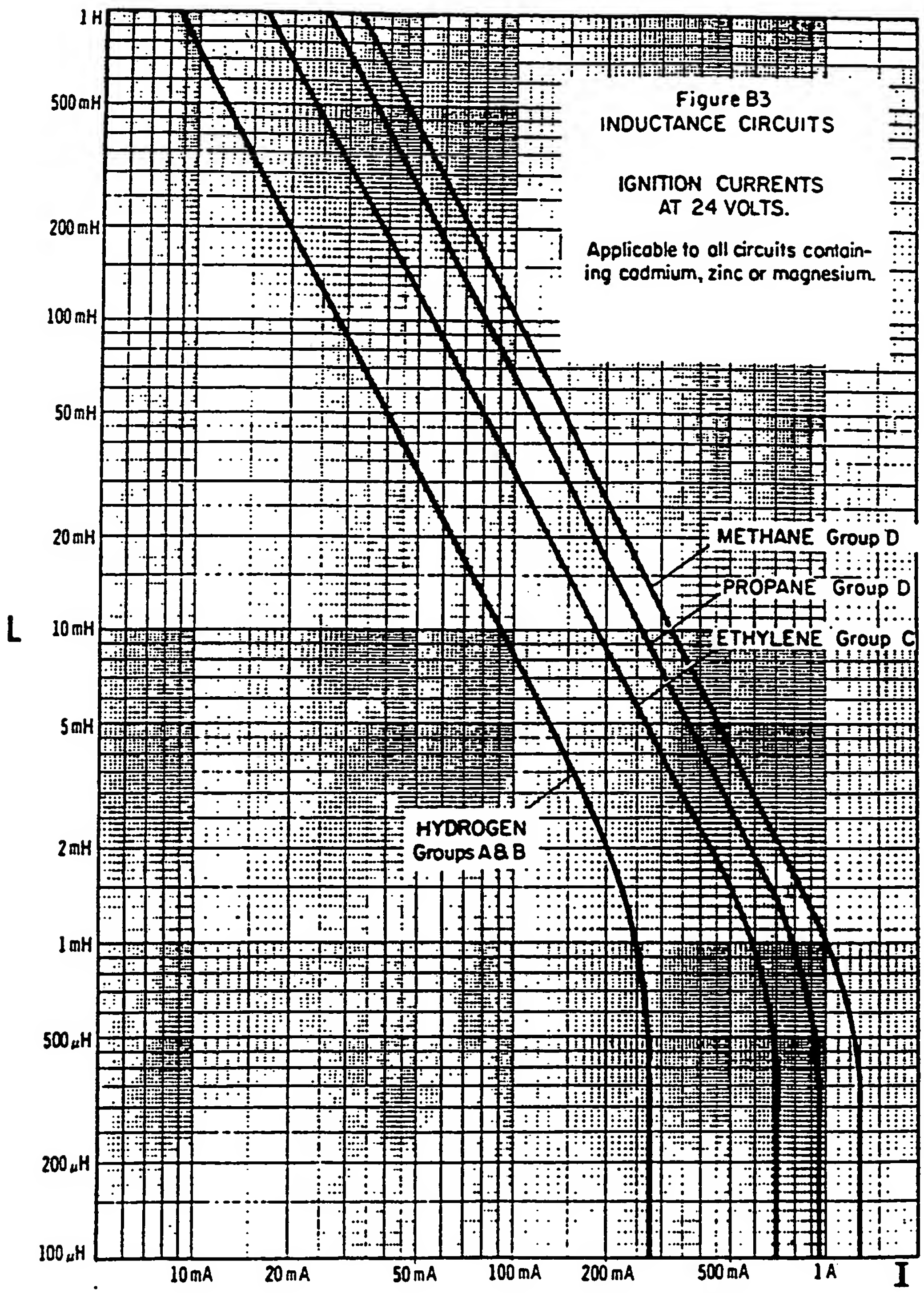


Figure B2
RESISTANCE CIRCUITS

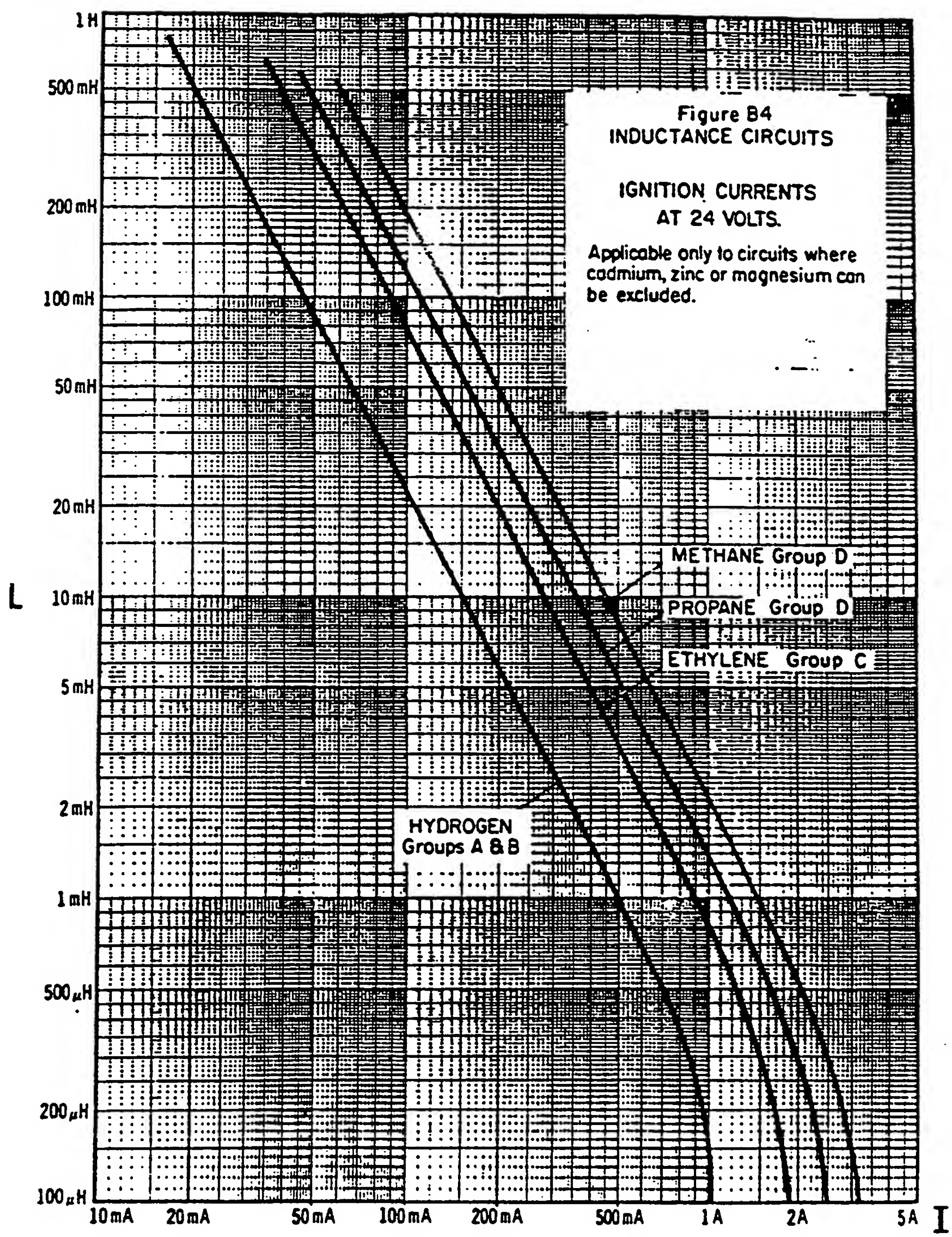
IGNITION CURRENTS

Applicable to circuits where cadmium, zinc or magnesium can be excluded.

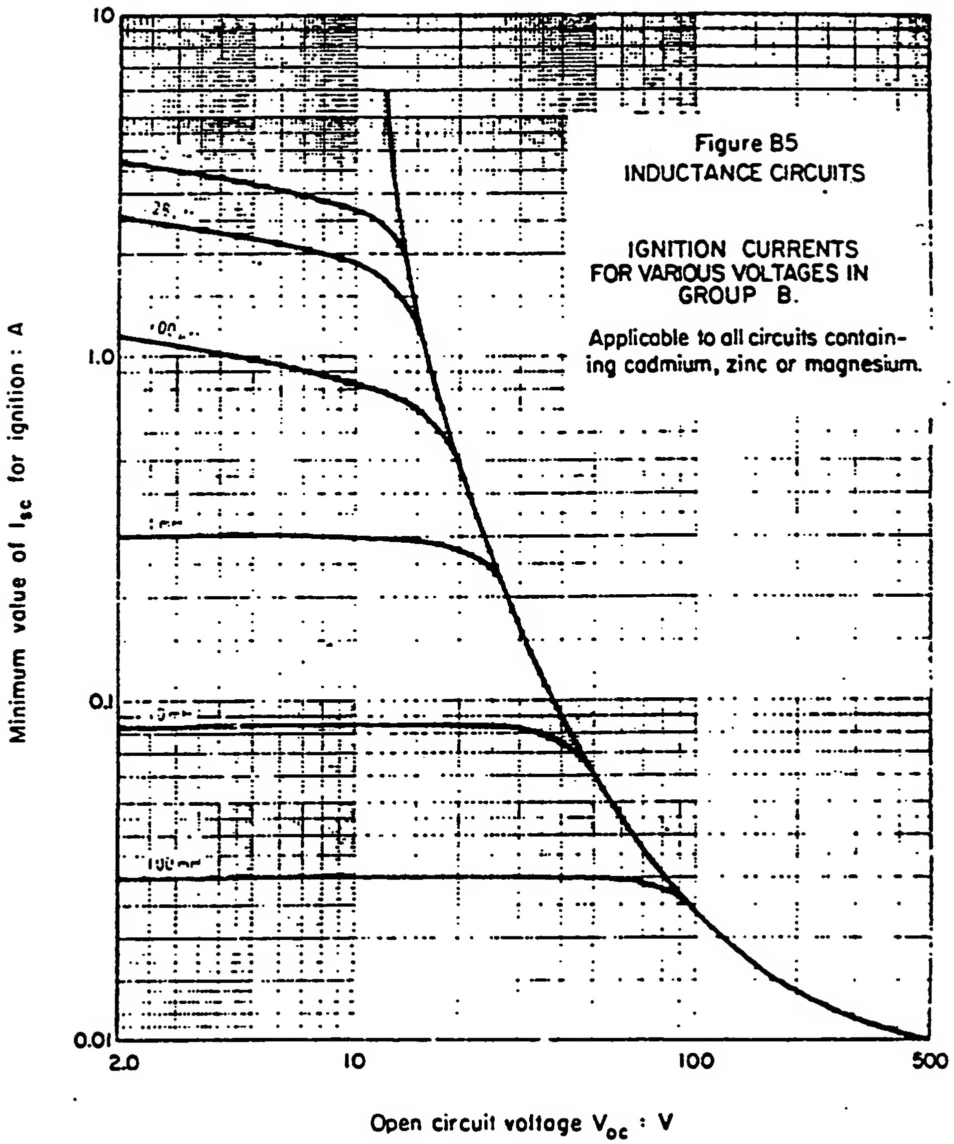
INDUCTANCE CIRCUITS
IGNITION CURRENTS AT 24 VOLTS



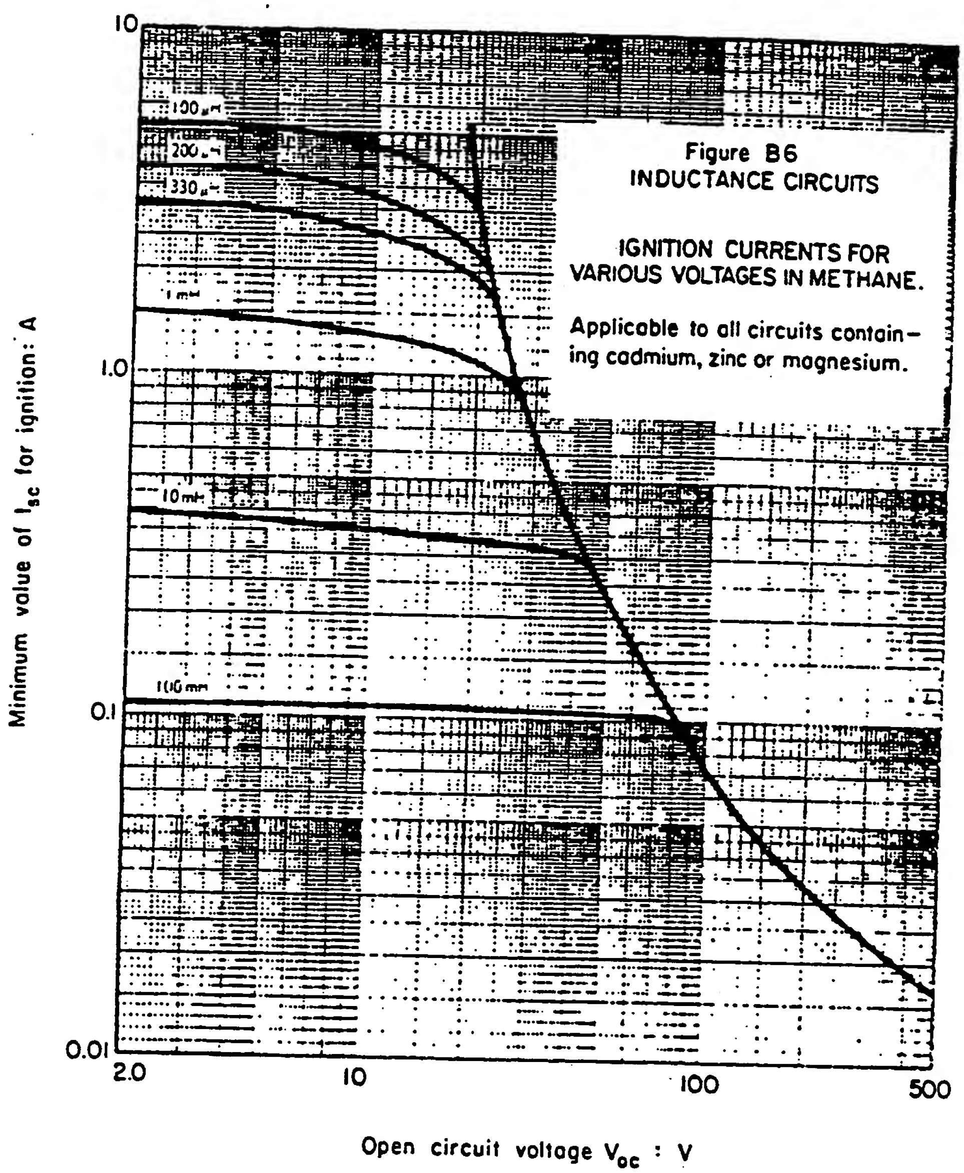
INDUCTANCE CIRCUITS
IGNITION CURRENTS AT 24 VOLTS



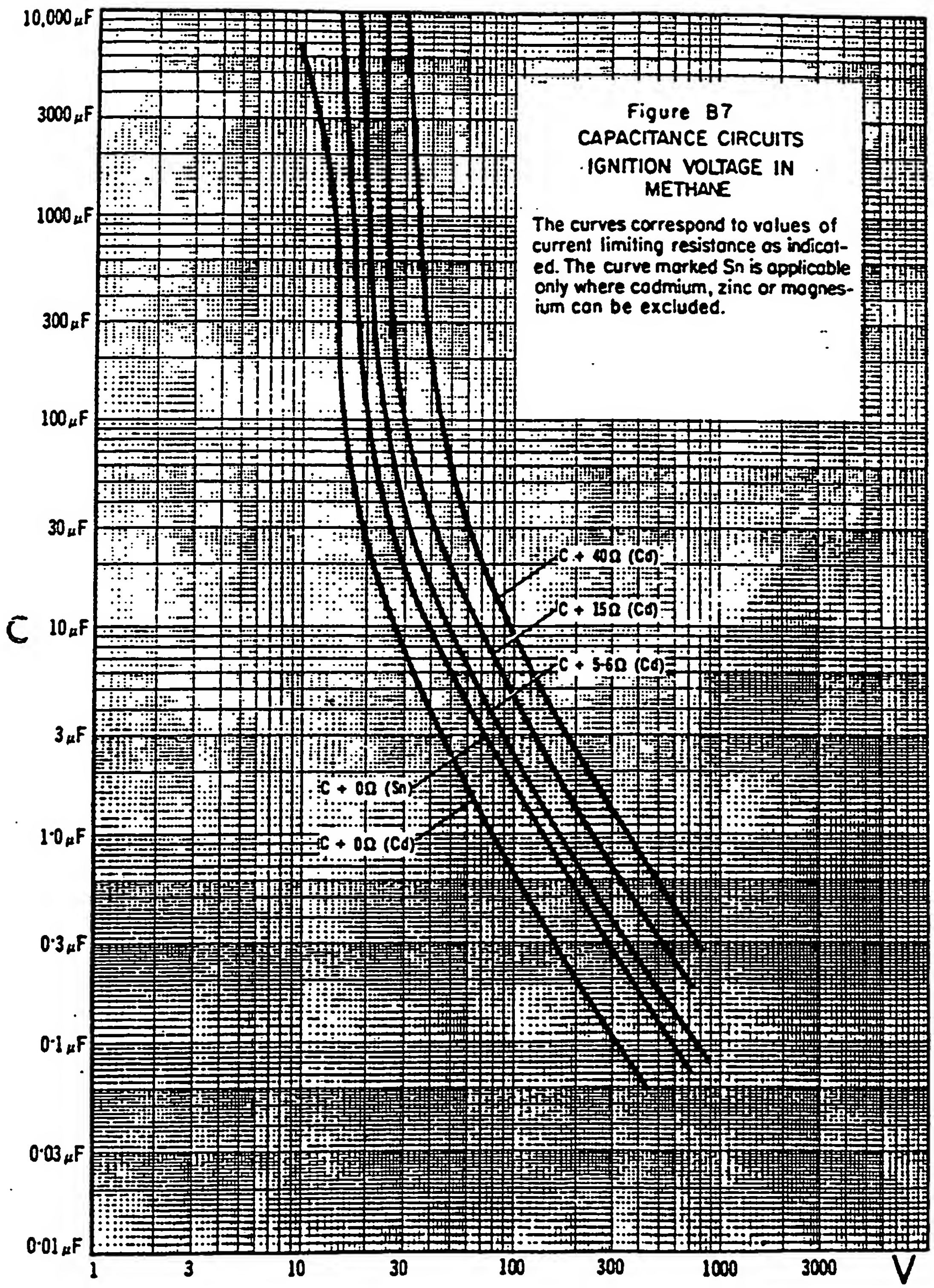
INDUCTANCE CIRCUITS
IGNITION CURRENTS AT VARIOUS VOLTAGES IN GROUP B



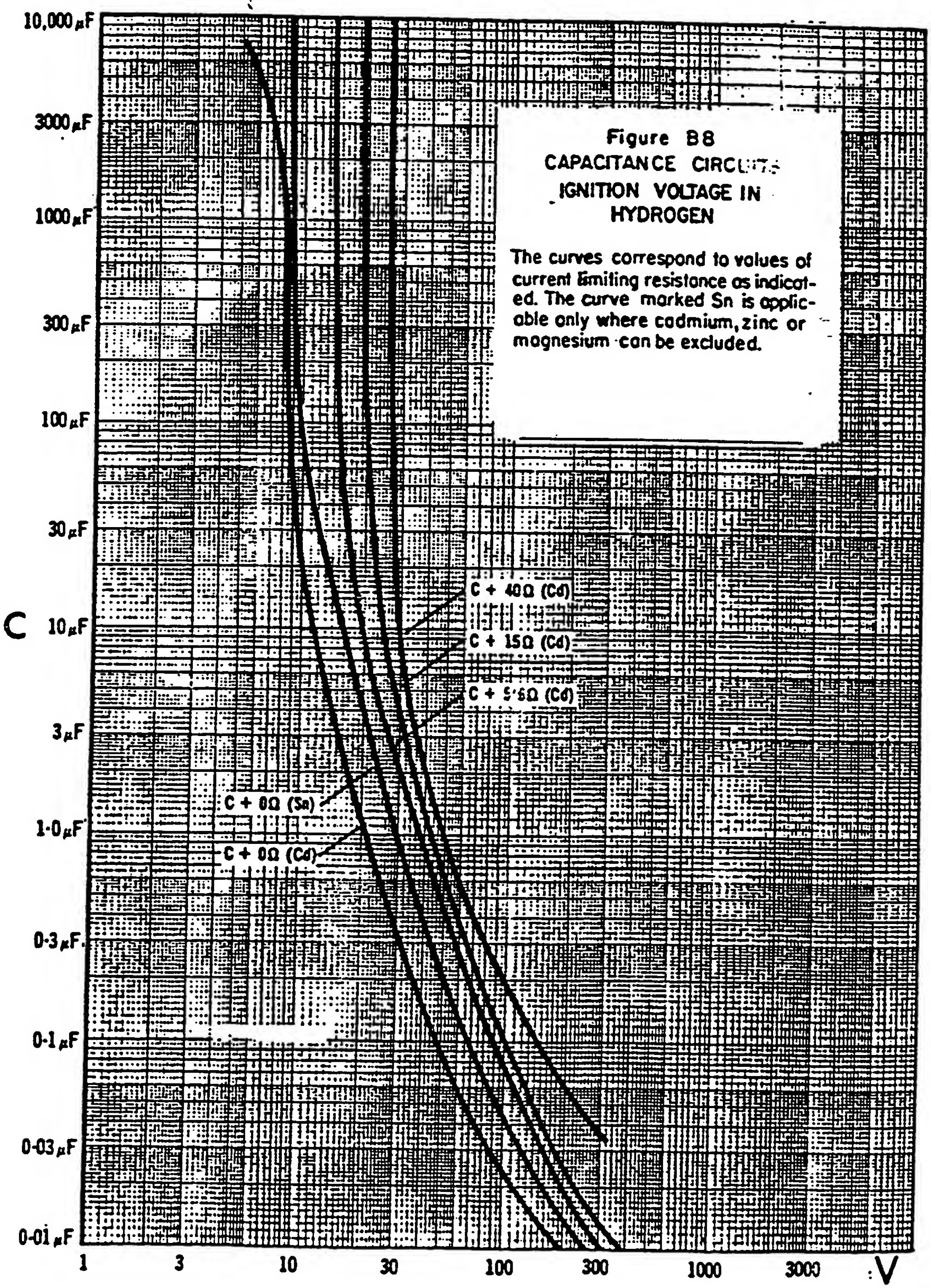
INDUCTANCE CIRCUITS
IGNITION CURRENTS AT VARIOUS VOLTAGES IN METHANE



CAPACITANCE CIRCUITS
IGNITION VOLTAGE IN METHANE



CAPACITANCE CIRCUITS
IGNITION VOLTAGE IN HYDROGEN



ENTITY CONCEPT EXAMINATION PROCEDURE

C1 The associated apparatus shall be evaluated under normal, single fault and two fault criteria with applicable factor on energy. Using the maximum open-circuit voltage and short-circuit current, with applicable factor, determine the allowable connected inductance and capacitance directly from the curves in Appendix B without applying an additional factor.

C2 The following shall be the method for determining the input parameters of intrinsically safe apparatus.

C2.1 Determine V max from the appropriate curve in Appendix B based on the maximum unprotected capacitance appearing at the input terminals of the intrinsically safe apparatus with up to two faults.

C2.2 Determine I max from the appropriate curve in Appendix B based on the maximum unprotected inductance appearing at the input terminals of the intrinsically safe apparatus with up to two faults.

C2.3 Determine analytically or experimentally, for the values of Vmax and Imax determined in C2.1 and C2.2, that the intrinsically safe apparatus will not produce an ignition capable component temperature for that combination of faults. Verify also that some lower current will not cause ignition capable hot spots for some other combination of two faults.

NOTE: THE MANUFACTURER MAY, AT HIS DISCRETION, SPECIFY A VOLTAGE LOWER THAN VMAX DETERMINED IN C2.1 FOR EVALUATION AND LABELING.

C3 The following method will be used to determine the parameters for markings.

C3.1 Allowable connected inductance and capacitance to associated apparatus shall be:

C3.1.1 Inductance (La) and Capacitance (Ca). Using the maximum open-circuit voltage and maximum short-circuit current of the associated apparatus, after considering faults and applicable factor on both voltage and current, determine the values of (La) and (Ca) directly from the curves in Appendix B.

C3.2 Unprotected internal capacitance and inductance of intrinsically safe apparatus shall be:

C3.2.1 Capacitance (Ci) and Inductance (Li).

(a) The value of capacitance (Ci) shall be as determined in C2.1.
(b) The value of inductance (Li) shall be as determined in C2.2.

C4 Application of L and C

When cable parameters are known, the system designer adds the parameters for lengths of cable to be used to the marked parameters of the intrinsically safe apparatus and compares the sum to the allowable parameter values for the associated apparatus. If the electrical parameters of the cable are unknown, the following values may be used:

Capacitance	60	pF/ft
Inductance	0.20	μH/ft

Based on a survey of manufacturer's data, few cables exceed either of these values.

APPROVAL MARKS

REPRODUCTION ART: Factory Mutual System Approval Marks

For use on nameplates, in literature, advertisements, packaging, and other graphics.

1) This is the official Factory Mutual System mark. It should never be reproduced in sizes smaller than 7/16 in. wide, the minimum size requirement for readability and identification. Color should be black and white, i.e., white lettering with black border.

2) When the mark must appear on a dark background but where the printing surface is white, such as an overall reverse advertisement, the logomark should be printed with a white outline to bring it out from the background.

3) The FM diamond, the earlier approval mark, is still an alternative. The diamond has no minimum size requirement, but it should always be large enough to be readily identifiable. Color should be black on a light background or a reverse may be used on a dark background.

NOTE: Use of the word "approved" with the above approval marks is mandatory. Positions of "approved" shown here are suggested for best form. Use of the word "approved" with the Cast-On Mark shown below is optional.

For Cast-On Marks

4) Where reproduction of one of the above marks is impossible because of production restrictions, a modified version of the diamond is suggested. Minimum size specifications are the same as for printed marks.

Additional repro art is available through the System Identification Coordinator, Factory Mutual Engineering and Research, Box 9102, Norwood, Massachusetts 02062

NOTE: These approval marks are to be used only in conjunction with products or services which have been approved by Factory Mutual Research Corp. The Factory Mutual approval symbol should never be used in any manner (including advertising, sales, or promotional purposes) that could suggest or imply Factory Mutual approval or endorsement of a specific manufacturer or distributor. Nor should it be implied that approval extends to a product or service not covered by written agreement with Factory Mutual. The approval mark signifies only that the product or service has met certain requirements as reported by Factory Mutual.

 Printed in U.S.A. P7150 (rev. 1984)

UNITS OF MEASUREMENT

LENGTH:	mm - "millimeters" (in. - "inches")
	in. = mm x 0.3937
AREA:	mm^2 - "square millimeters" (in^2 - "square inches")
	in^2 = mm^2 x 1.550 x 10^{-3}
	m^2 - "square meters" (ft^2 - "square feet")
	ft^2 = m^2 x 10.76
TEMPERATURE:	°C - "degrees Celsius" (°F - "degrees Fahrenheit)
	°F = °C x 9/5 + 32
PRESSURE:	kPa - "kilopascals" (psi - pounds per square inch")
	psi = kPa x 0.1450
FORCE:	N - "newtons" (lbf - "pound-force")
	lbf = N x 0.2248
ENERGY:	J - "joules' (ft•lbf - "foot pound-force)
	ft•lbf = J x 0.7375
FREQUENCY:	Hz - "hertz" (Also the SI unit)

Factory Mutual System

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Class No. 3610 October 1988

APPROVAL STANDARD
INTRINSICALLY SAFE APPARATUS
AND ASSOCIATED APPARATUS
FOR USE IN
CLASS I, II AND III, DIVISION 1
HAZARDOUS (CLASSIFIED) LOCATIONS

NOTICE: The asterisk (*) following the subsection number signifies that explanatory material on that paragraph appears in Appendix A.

I INTRODUCTION

1.1 PURPOSE

This standard serves as the basis for Factory Mutual Approval of intrinsically safe apparatus and associated apparatus.

1.2 SCOPE

This standard provides requirements for the construction and testing of electrical apparatus, or parts of such apparatus, whose circuits are incapable of causing ignition in Division 1 hazardous locations as defined in Article 500 of the National Electrical Code, NFPA-70. This standard is intended to be used in conjunction with Class 3600 Approval Standard which includes the general requirements that apply to all types of classified location protection methods.

1.3 BASIS FOR FACTORY MUTUAL APPROVAL

See Approval Standard 3600, Section 1.3.

1.4 BASIS FOR CONTINUED APPROVAL

Continued Approval is based upon:

- production or availability of the product as currently Approved;
- the continued use of acceptable quality control procedures;
- satisfactory field experience;
- compliance with the terms stipulated in the Approval Agreement; and
- re-examination, as necessary, of production samples for continued conformity to requirements.

1.5 BASIS FOR REQUIREMENTS

1.5.1 The requirements of this standard are based on experience, research and testing and/or the standards of other national and international organizations. The advice of manufacturers, users, trade associations and loss control specialists was also considered.

1.5.2 The requirements of this standard reflect tests and practices used to examine characteristics of intrinsically safe apparatus for the purpose of obtaining Factory Mutual Approval. These requirements are intended primarily as guides, and strict conformity is not always mandatory. Devices having characteristics not anticipated by this standard may be Approved if performance equal or superior to that required by this standard is demonstrated, or if the intent of the standard is met. Alternatively, devices which do meet all the requirements identified in this standard may not be Approved if other conditions which adversely affect performance exist or if the intent of this standard is not met.

1.5.3 The construction, tests and marking required by this standard correspond, in general, to the American National Standard for Intrinsically Safe Apparatus and Associated Apparatus For Use In Class I, II and III, Division 1 Hazardous Locations. The American National Standard was the result of extensive committee activity and analysis, coupled closely with previous work done by the Instrument Society of America and the International Electrotechnical Commission.

1.6 EFFECTIVE DATE

The effective date of an Approval Standard mandates that all products tested for Approval after the effective date shall satisfy the requirements of that standard. Products Approved under a previous edition shall comply with the new version by the effective date or else forfeit Approval. The effective date shall apply to the entire Approval Standard, or, where so indicated, only to specific paragraphs of the standard.

The effective date of this standard is JANUARY 1, 1992, for full compliance with all requirements.

1.7 SYSTEM OF UNITS

Units of Measurement are International System (SI) units. These are followed by their arithmetic equivalents in English System standard units, enclosed in parentheses. Appendix E lists the selected units for quantities dealt with in testing these products; conversions to English units are included. Conversion of customary units is in accordance with ASTM E 380.

HOW TO APPLY FOR AN APPROVAL EXAMINATION

Send a letter requesting an examination addressed to:

Instrumentation Section Manager
Factory Mutual Research Corporation
1151 Boston-Providence Turnpike
Norwood, Massachusetts 02062

The letter should indicate the Class(s), Division(s) and Group(s) for the hazardous locations the examination is to cover.

One copy of the following documentation should be submitted, logically organized and neatly assembled.

(a) A complete list of all models and options by Class, Division and Group.

(b) A list of major or specific use application of the equipment.

(c) A system block diagram showing the location (i.e., hazardous or nonhazardous location) and inter-connection of equipment.

(d) Installation, operation, and maintenance instructions.

(e) Circuit physical layout drawing(s), schematic(s), and parts lists.

(f) Assembly drawings showing overall physical separation of safe and unsafe circuits if not shown in circuit layout drawing.

(g) Drawings, specifications, and source control information for all protective components.

(h) Quality control documentation, and test procedures for all protective components and assemblies.

(i) Drawing(s) showing proposed labels to be applied to final product(s).

(j) If available, test report(s) by internationally recognized testing laboratories (e.g., CSA, PTB, BASEEFA).